Atmospheric Mining in the Outer Solar System: Design Options and Observational Systems

20th Advanced Space Propulsion Workshop
NASA / OAI
Cleveland, OH

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November 2014

Introduction

- Why atmospheric mining?
- Uninhabited Aerial Vehicles (UAVs), cruisers for weather reconnaissance, monitoring, etc.
- Engine issues.
  - Gas core engines, closed cycle.
  - Nuclear ramjets and rockets
- Resource capturing: helium 3, hydrogen, helium.
- UAV mission planning and options
- Observations
- Concluding remarks.

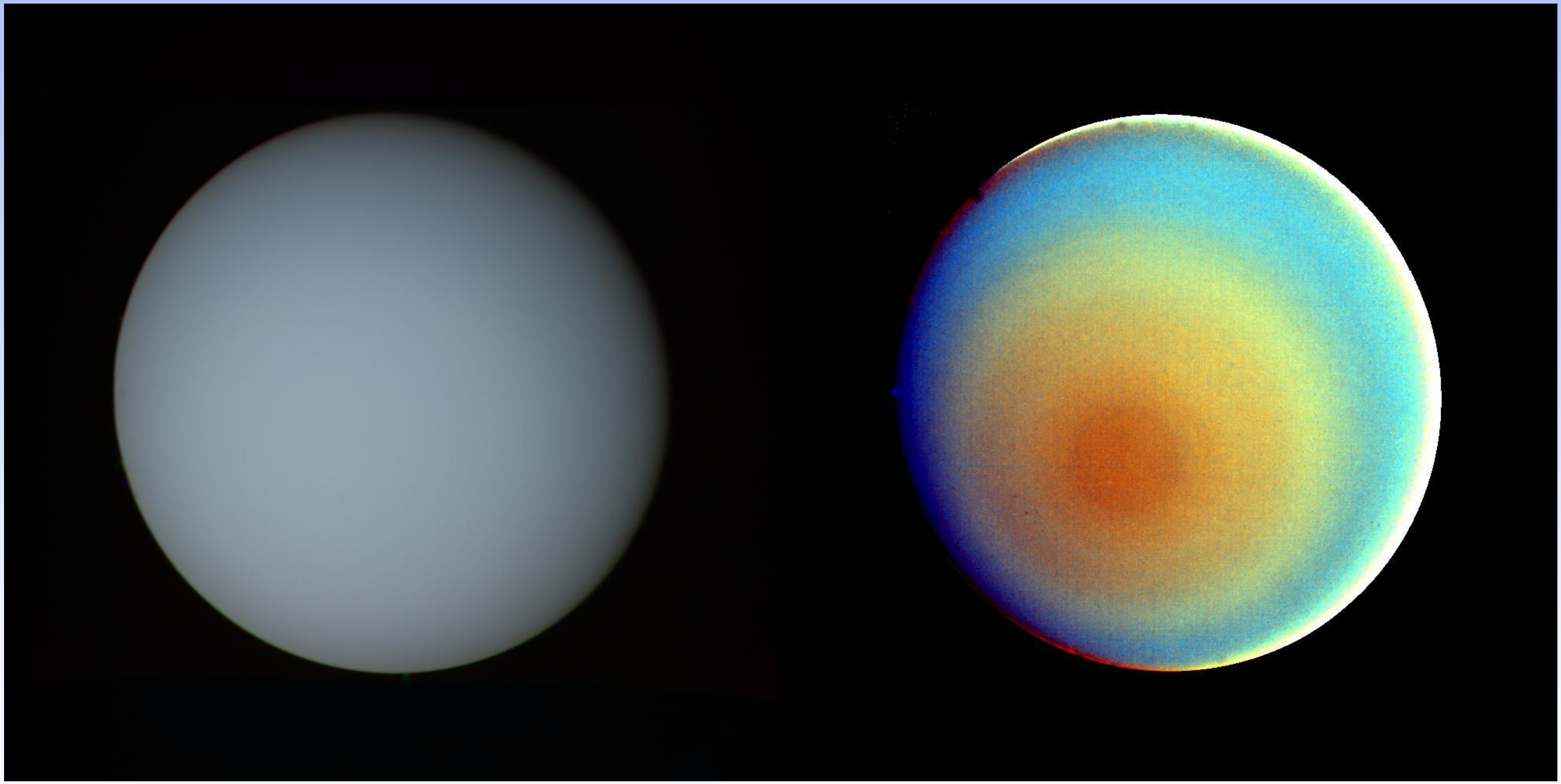
In Situ Resource Utilization (ISRU)

- In Situ Resource Utilization uses the materials from other places in the solar system to sustain human exploration
- Using those resources reduces the reliance on Earth launched mass, and hopefully reduces mission costs
- There are powerful capabilities to free humans from Earth

Why Atmospheric Mining?

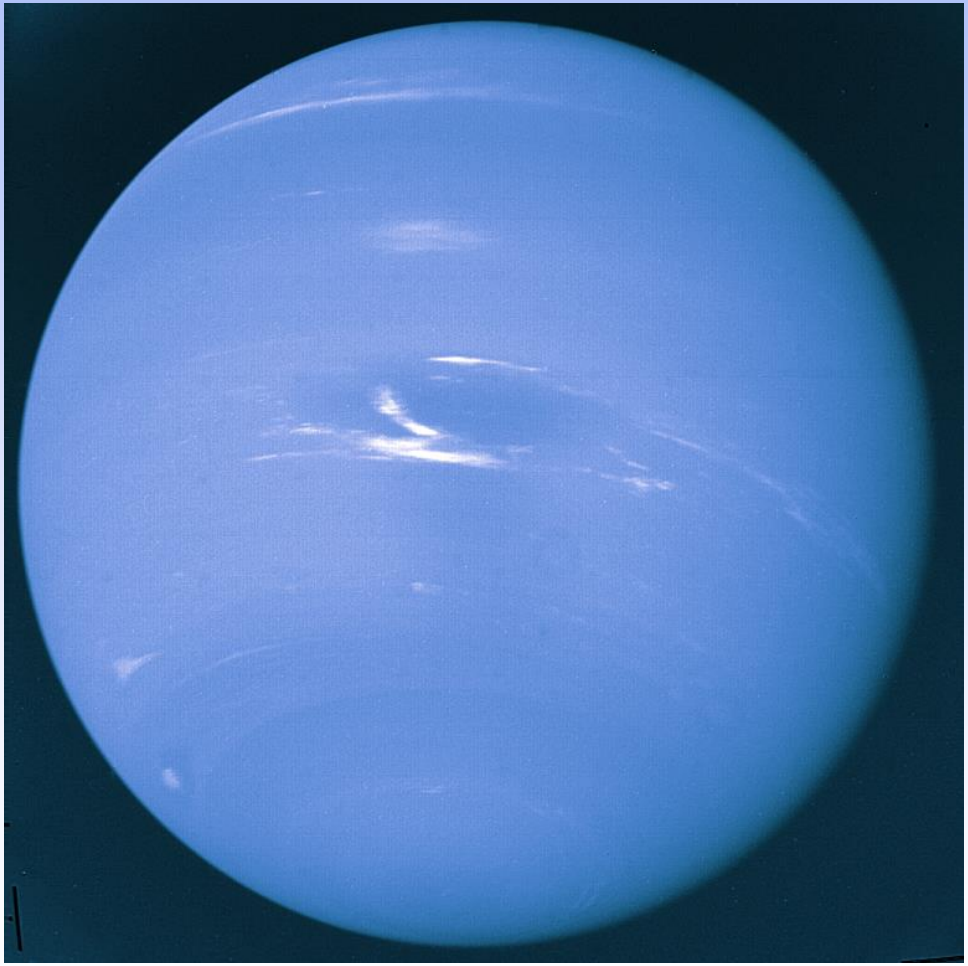
- Benefits:
  - Large amount of matter to mine (hydrogen and helium 3)
  - Potentially easier than mining regolith (dust) and rock
  - Larger reservoir of materials not readily available in regolith (and in a gaseous state)
- Potential drawbacks
  - Dipping deep into the gravity well of planets is expensive for propulsion systems
  - Lifetime of systems
  - Repetitive maneuvers
  - Cryogenic atmospheric environments
  - Long delivery pipelines

Uranus



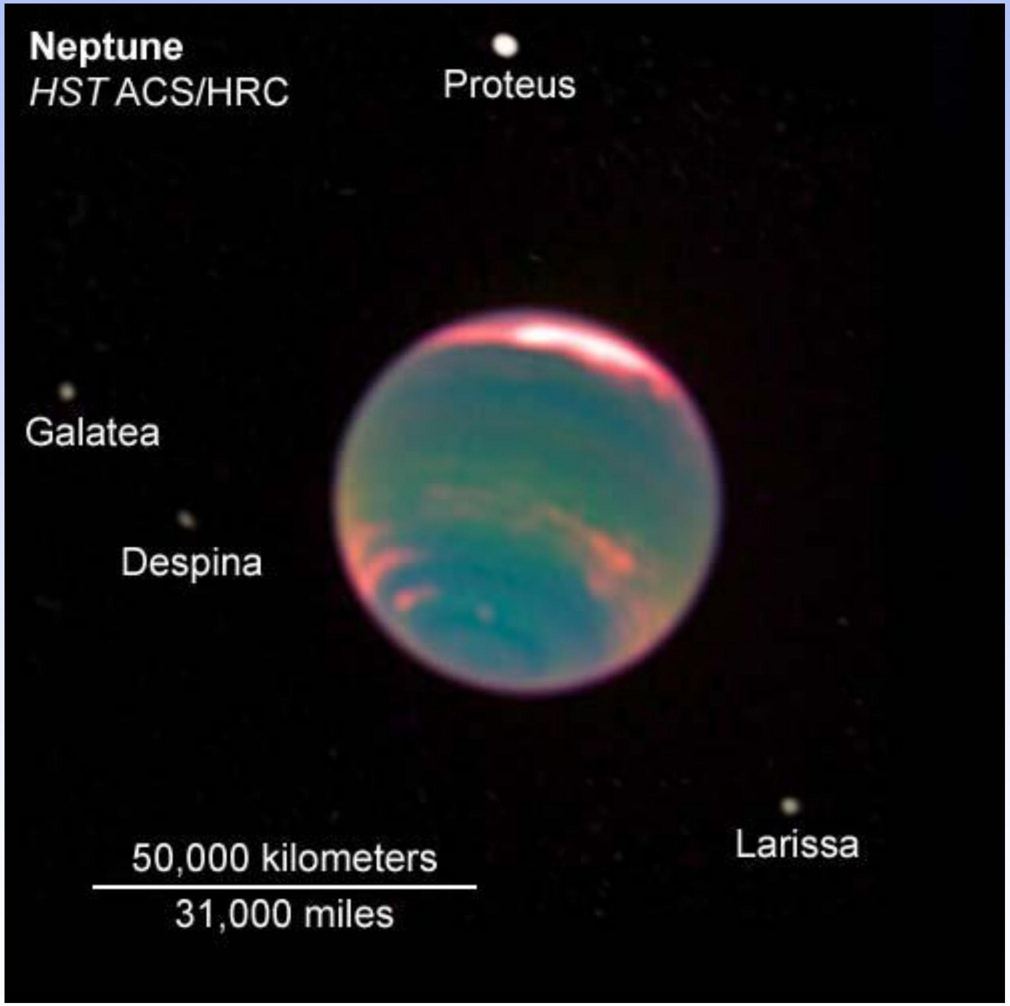
JPL

Neptune

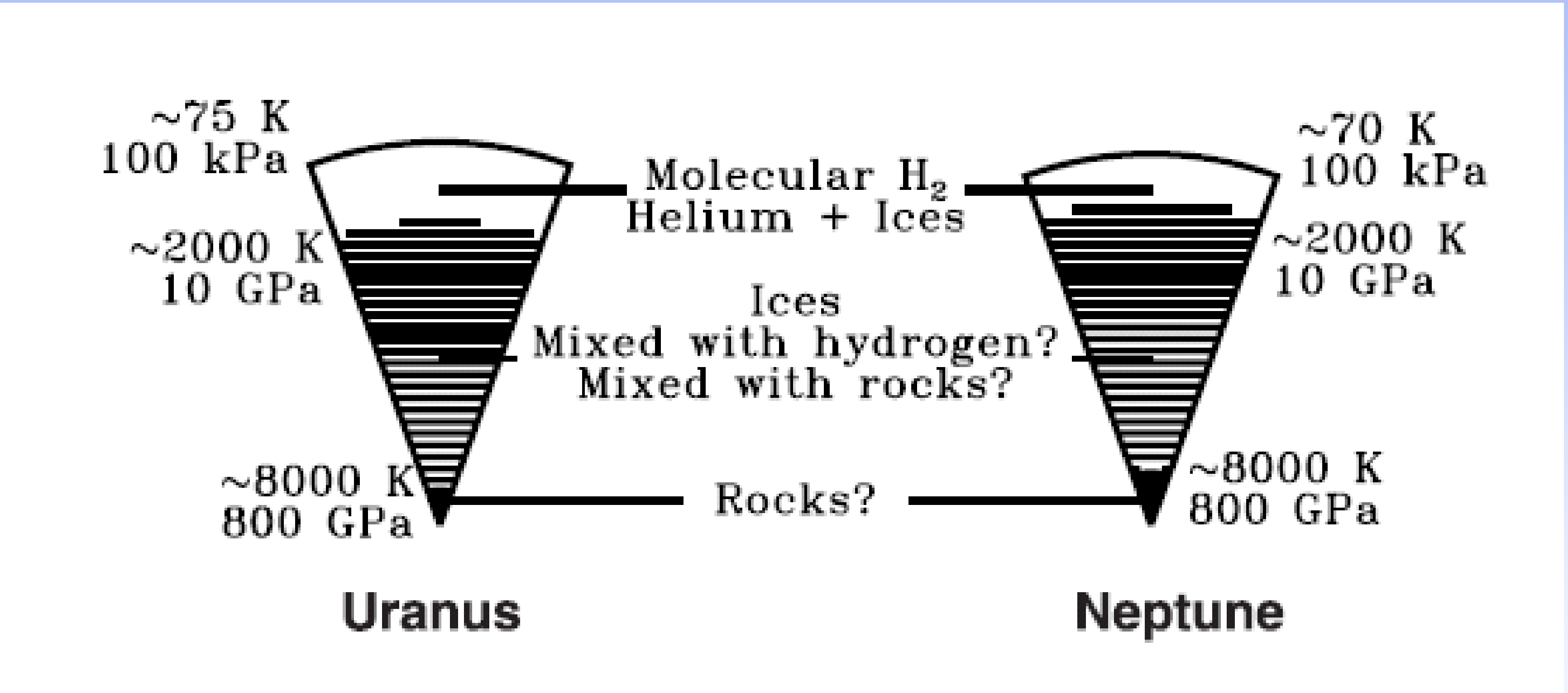


JPL

Neptune and Moons

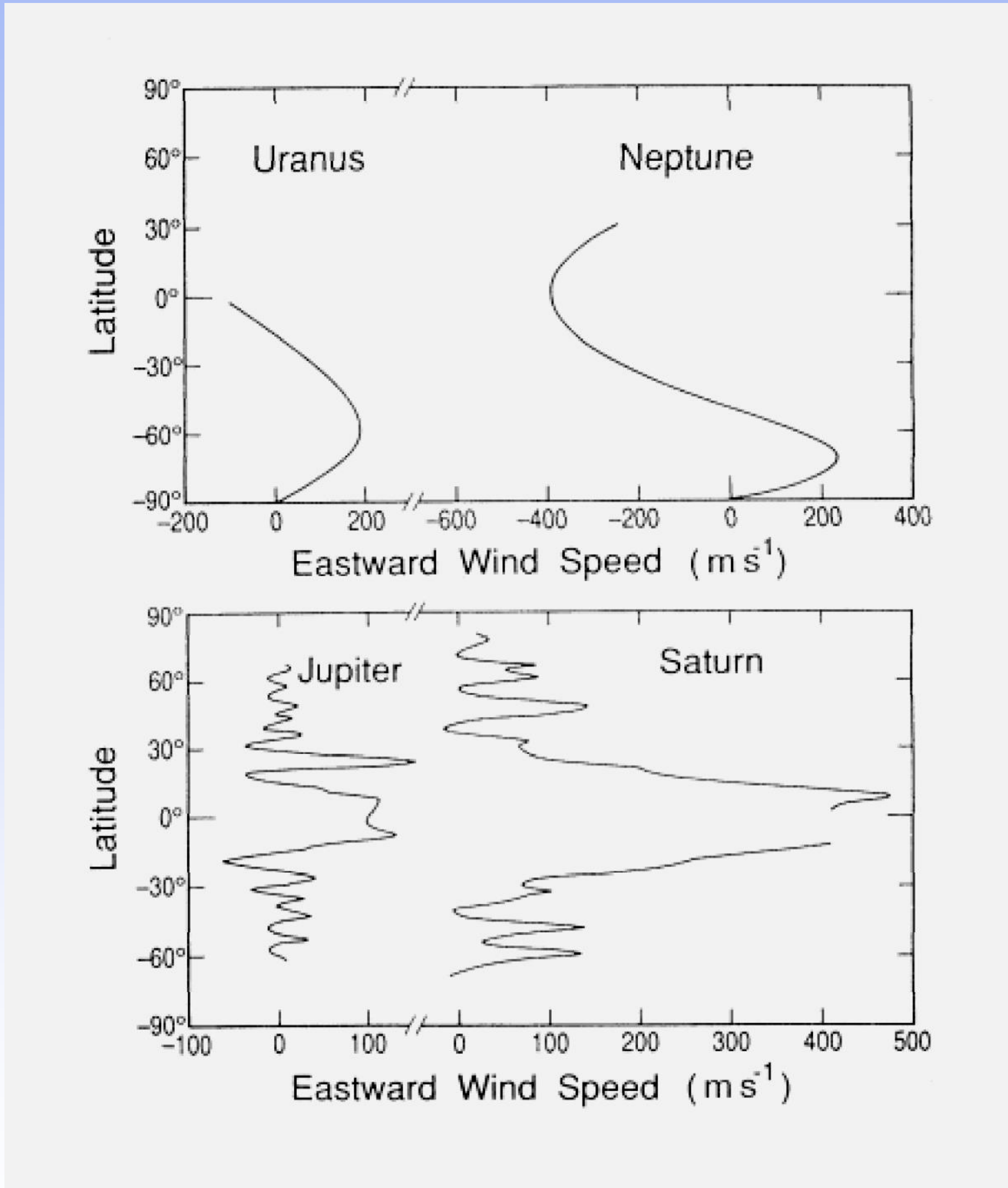


Outer Planet Atmospheres



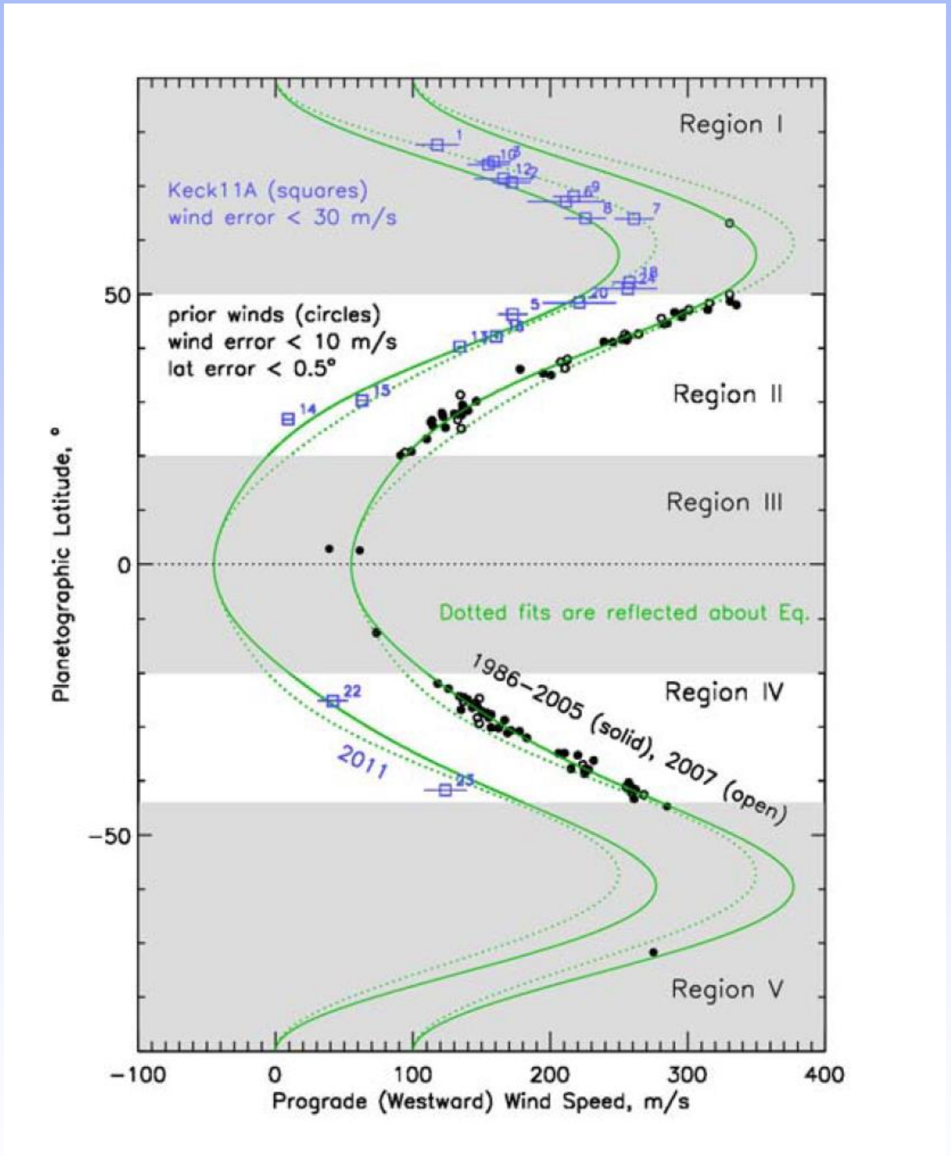
Tristan Guillot, "Interiors of Giant Planets Inside and Outside the Solar System."

Outer Planet Atmospheres and Wind Speeds



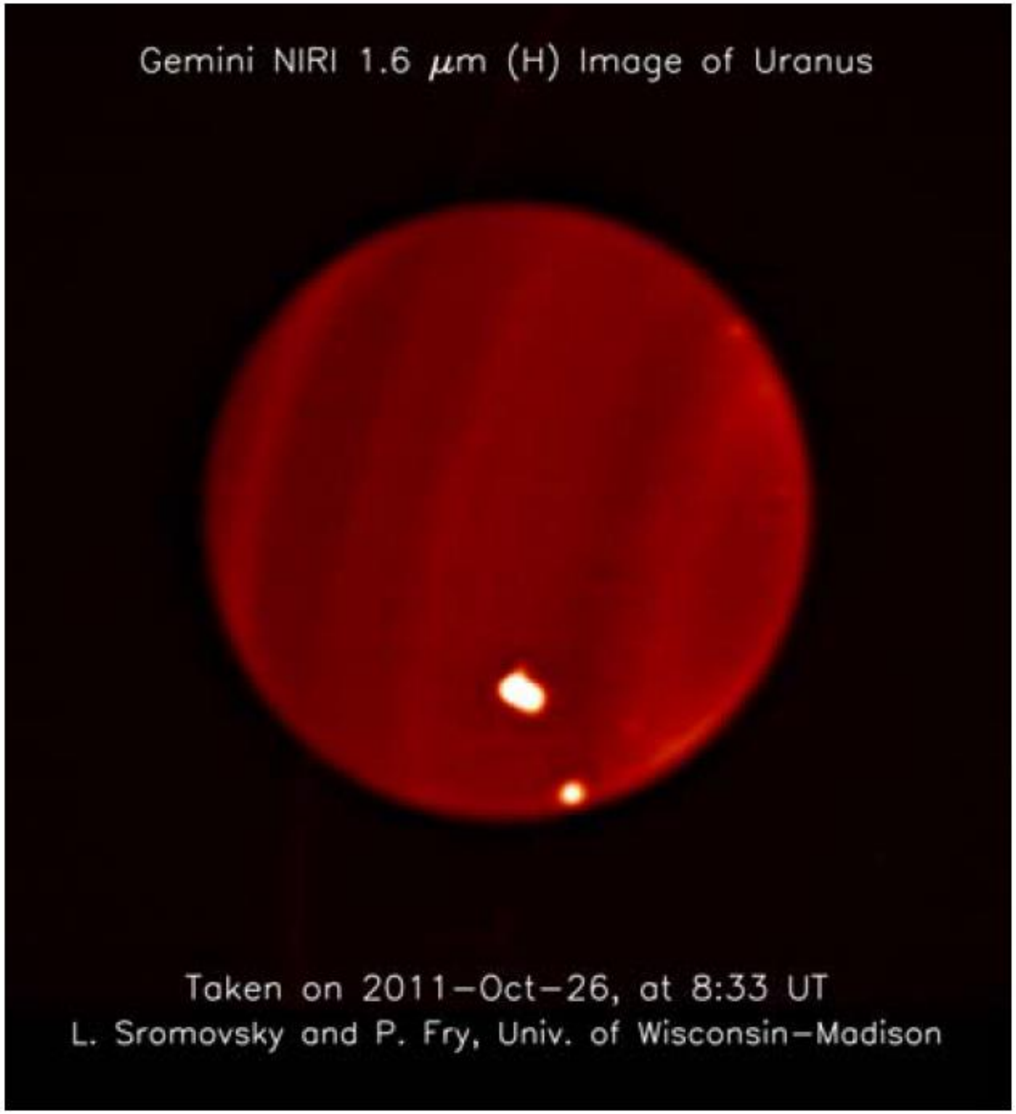
JPL, Ingersoll

Uranus – Outer Planet Atmospheres and Wind Speeds



Sromovsky, L., 2010, Investigating Atmospheric Change on Uranus and Neptune, Award number NNG05GF00G.

Uranus – Outer Planet Atmospheres and Wind Speeds



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UAV Configurations: Weather (3a/4)

Contents lists available at SciVerse ScienceDirect
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Episodic bright and dark spots on Uranus

L.A. Sromovsky[a,*], H.B. Hammel[b], I. de Pater[c], P.M. Fry[a], K.A. Rages[d], M.R. Showalter[d], W.J. Merline[e], P. Tamblyn[e], C. Neyman[f], J.-L. Margot[g], J. Fang[g], F. Colas[h], J.-L. Dauvergne[i], J.M. Gómez-Forrellad[j], R. Hueso[k], A. Sánchez-Lavega[k], Thomas Stallard[l]

UAV Configurations: Weather (3a/4)

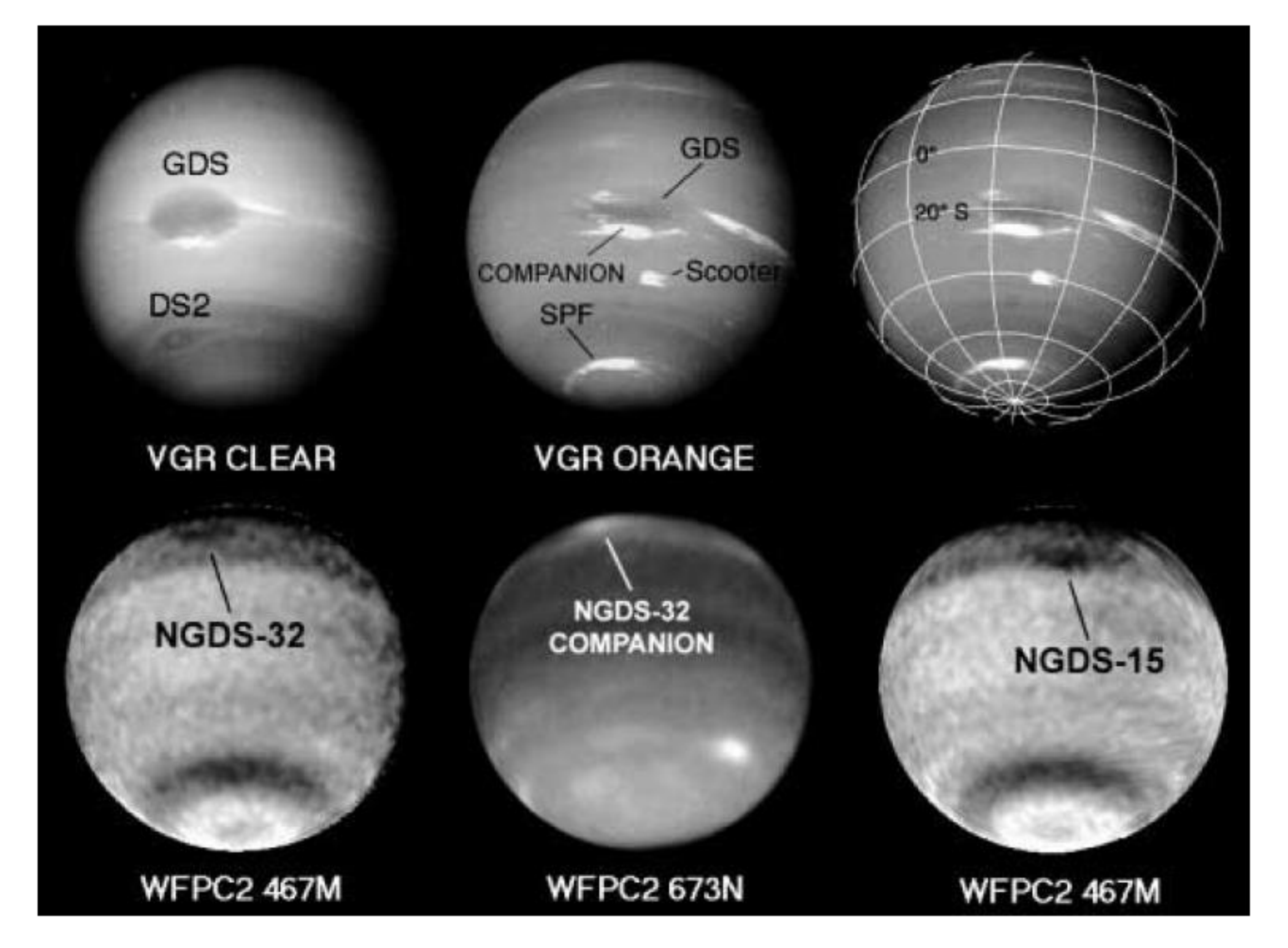
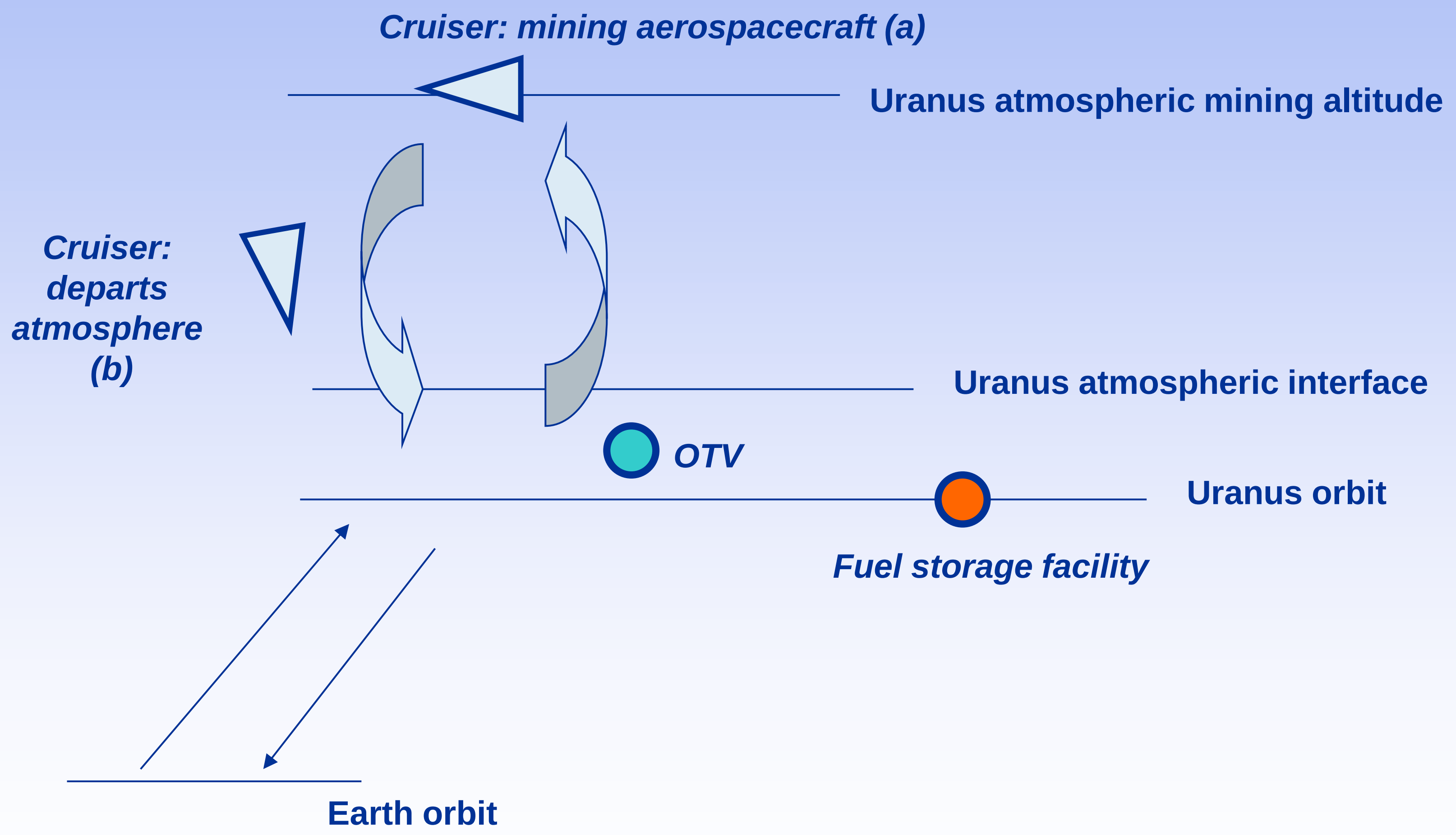


Figure B3. Neptune cloud features (Voyager, Hubble, Ref. 27)

Orbital Velocities: 10 km altitude

Planet	Delta-V (km/s)	Comment
Jupiter	41.897	BIG
Saturn	25.492	BIG
Uranus	15.053	More acceptable
Neptune	16.618	More acceptable

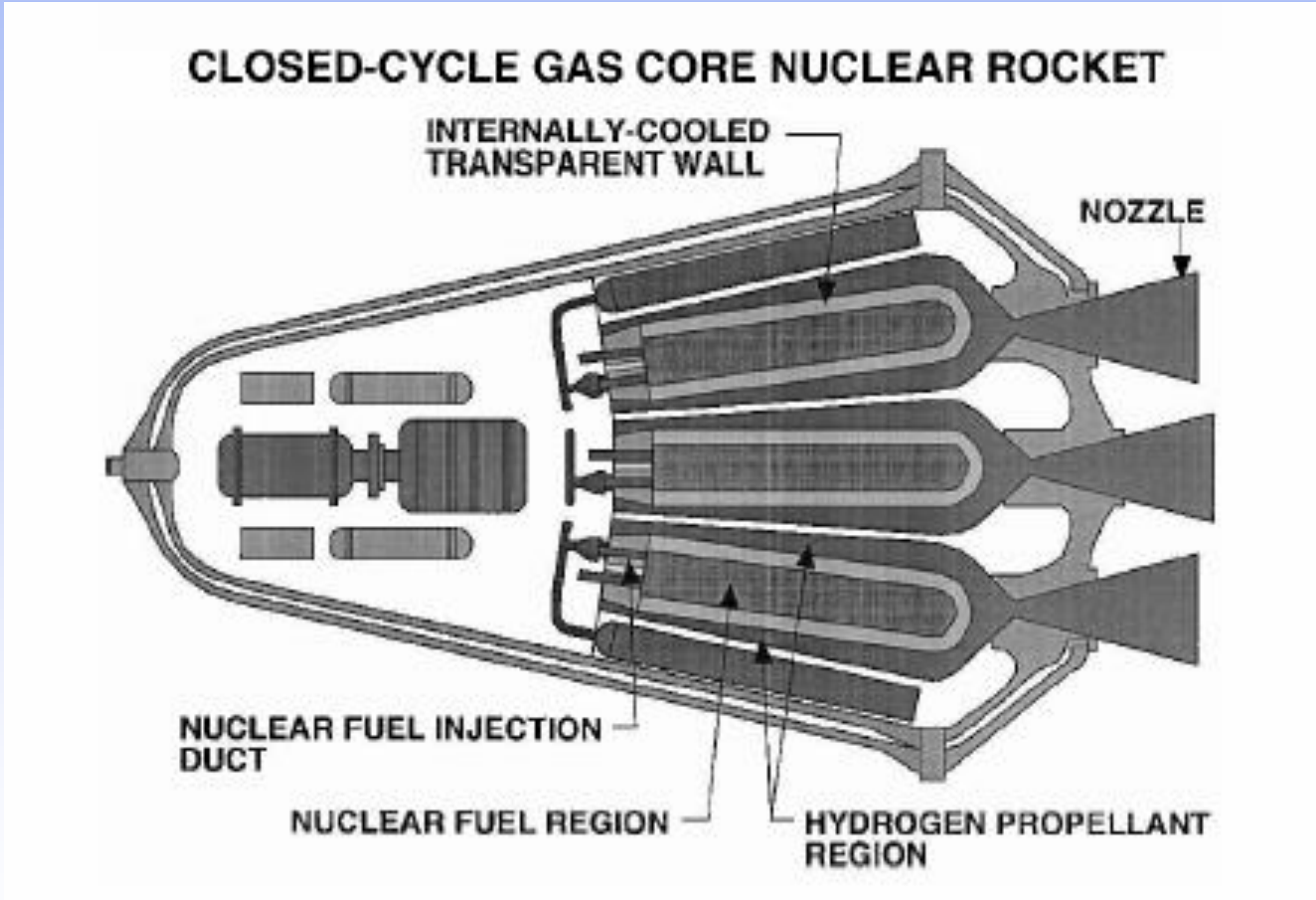
Cruiser Mining (1)
Combined Miner and Aerospacecraft



Mining Scenarios and OTVs

- Using cruiser aerospacecraft for mining in the atmosphere at subsonic speeds.
- Cruiser aerospacecraft then ascends to orbit, transferring propellant payload to orbital transfer vehicles (OTV).
- OTV will be the link to interplanetary transfer vehicle (ITV) for return to Earth.
- Moon bases for a propellant payload storage option was investigated.

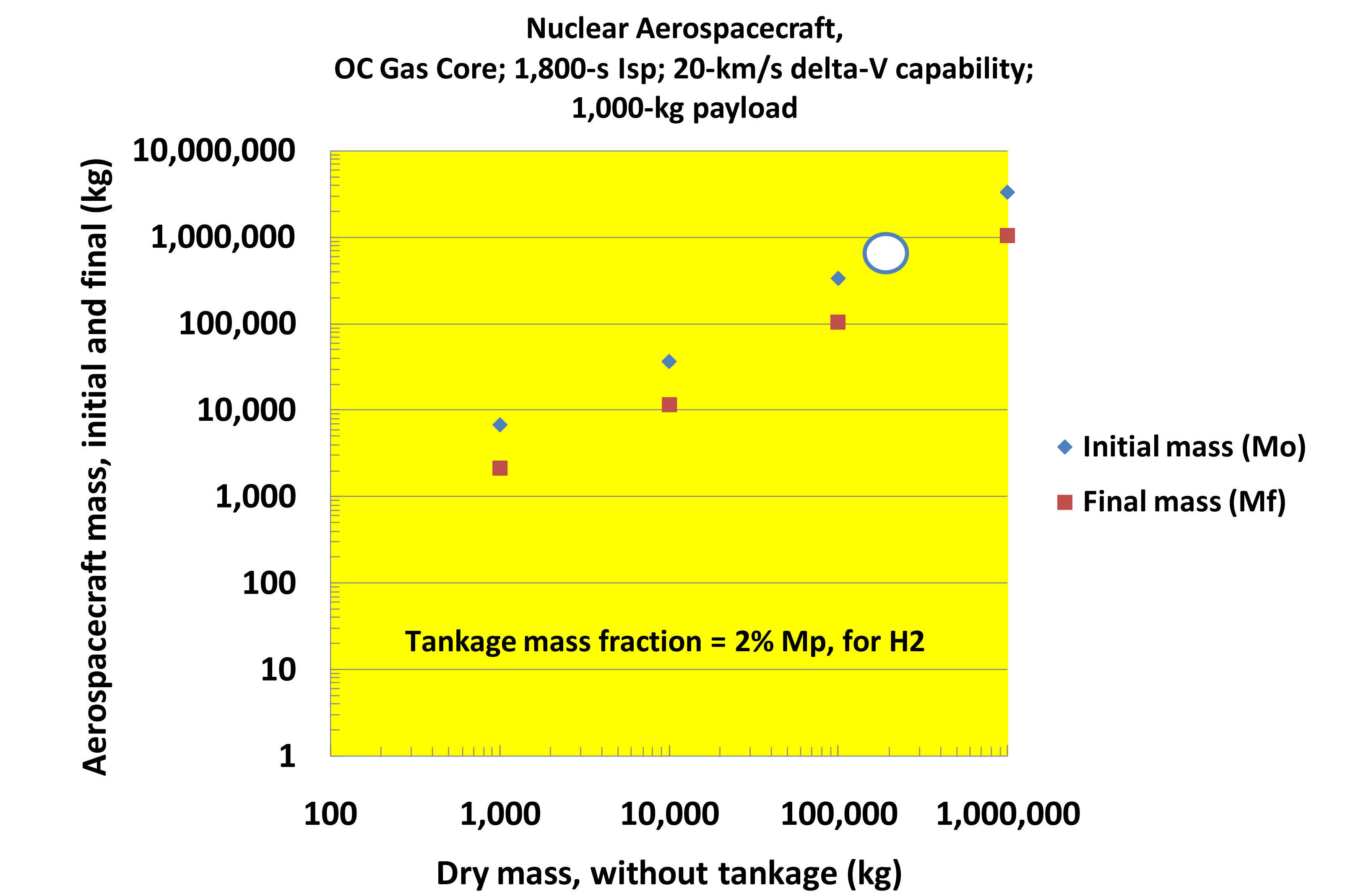
AMOSS GCR Designs



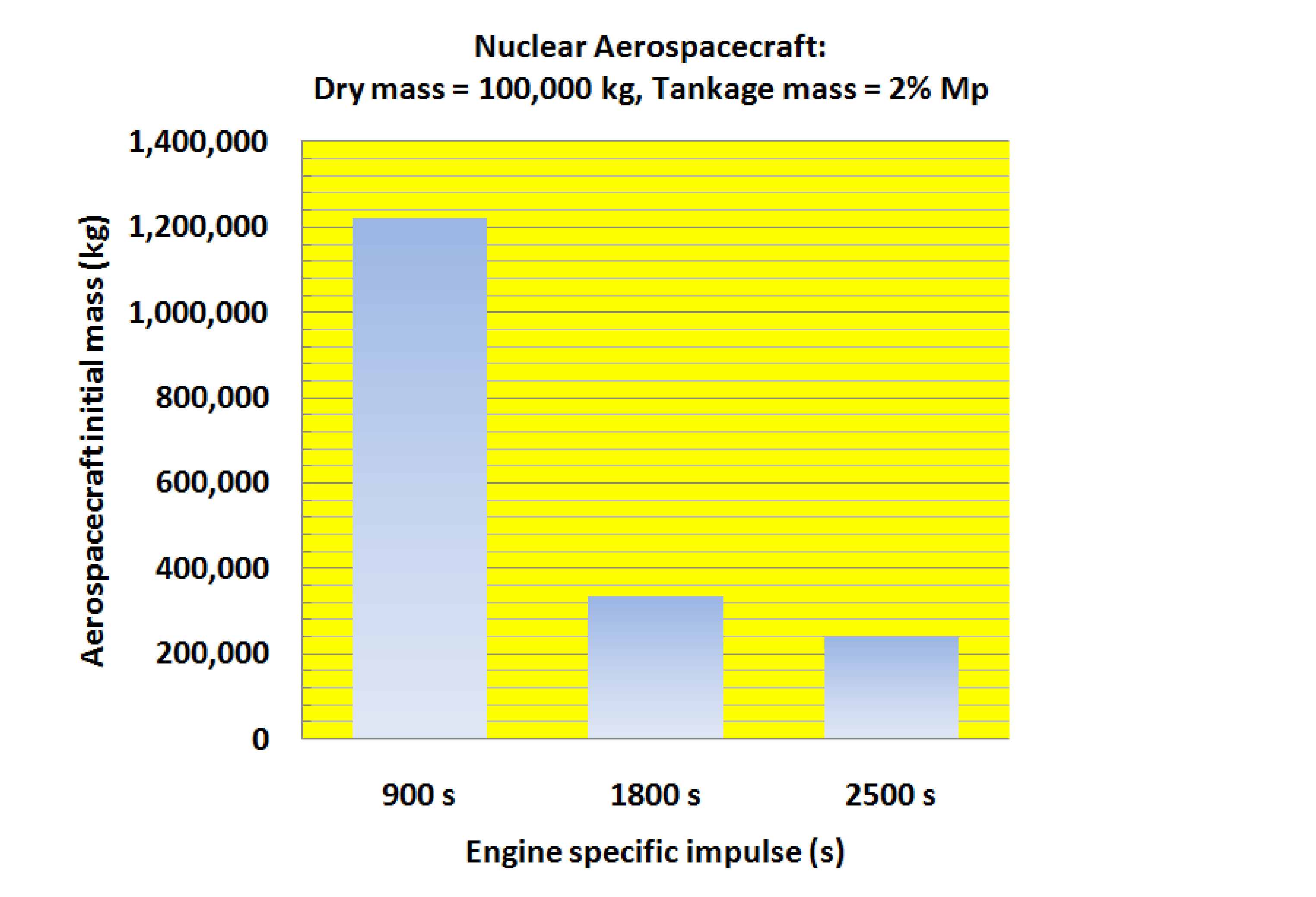
Gas Core Design and Analysis Overview

- Total aerospacecraft vehicle delta-V is 20 km/s.
- Single stage aerospacecraft.
- Gas core Isp values = 1800 and 2500 seconds
- Vehicles mass estimated over a broad range of dry masses.
- Dry mass (other than tankage) = 1,000, 10,000, 100,000, and 1,000,000 kg.
  - Typical gas core dry mass = 80,000 to 200,000 kg.
- Tankage mass = 2% and 10% of propellant mass.
- Comparative case: solid core NTP Isp = 900 seconds.

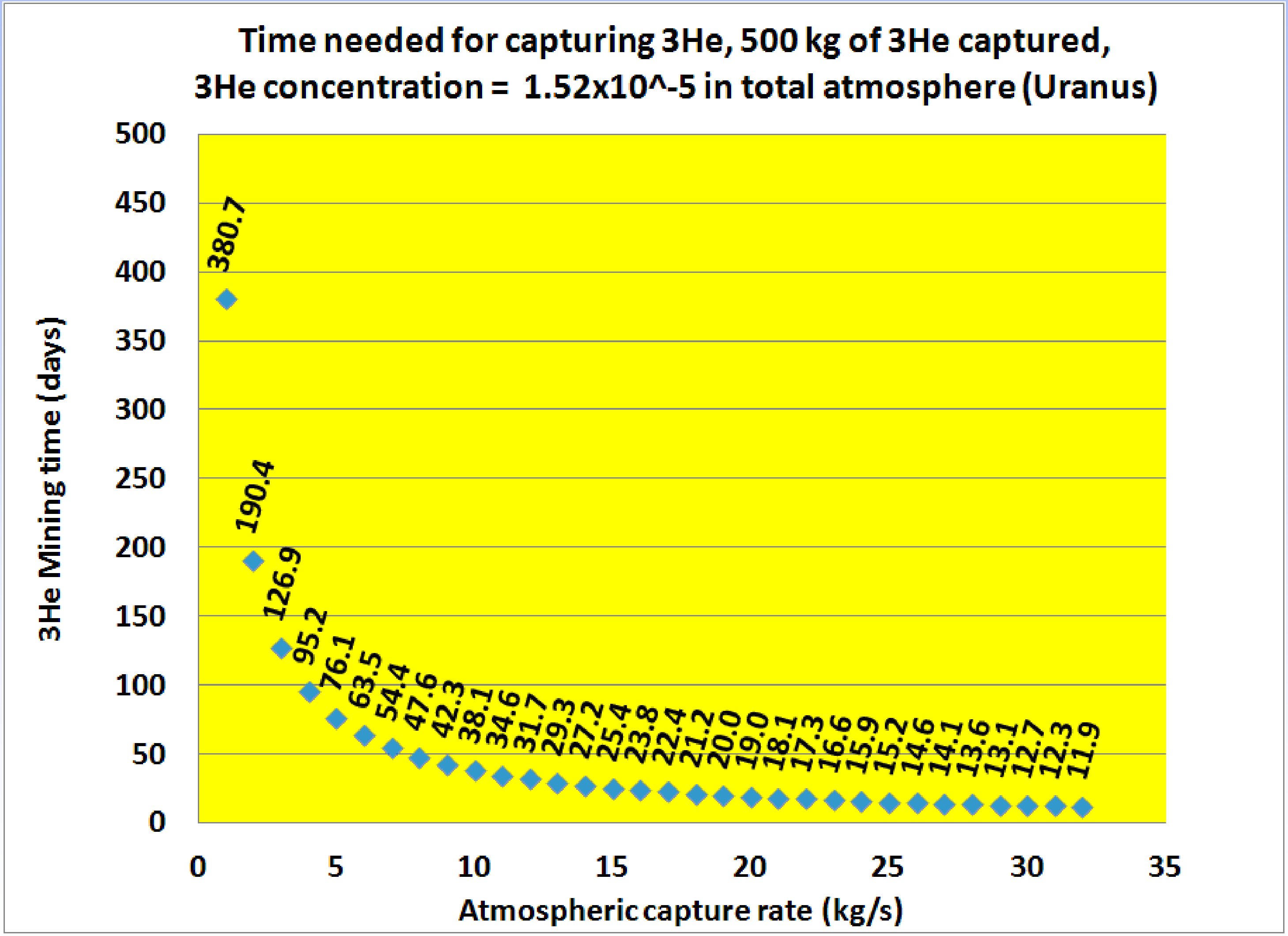
Gas core, Isp = 1,800 s, Tankage = 2% Mp



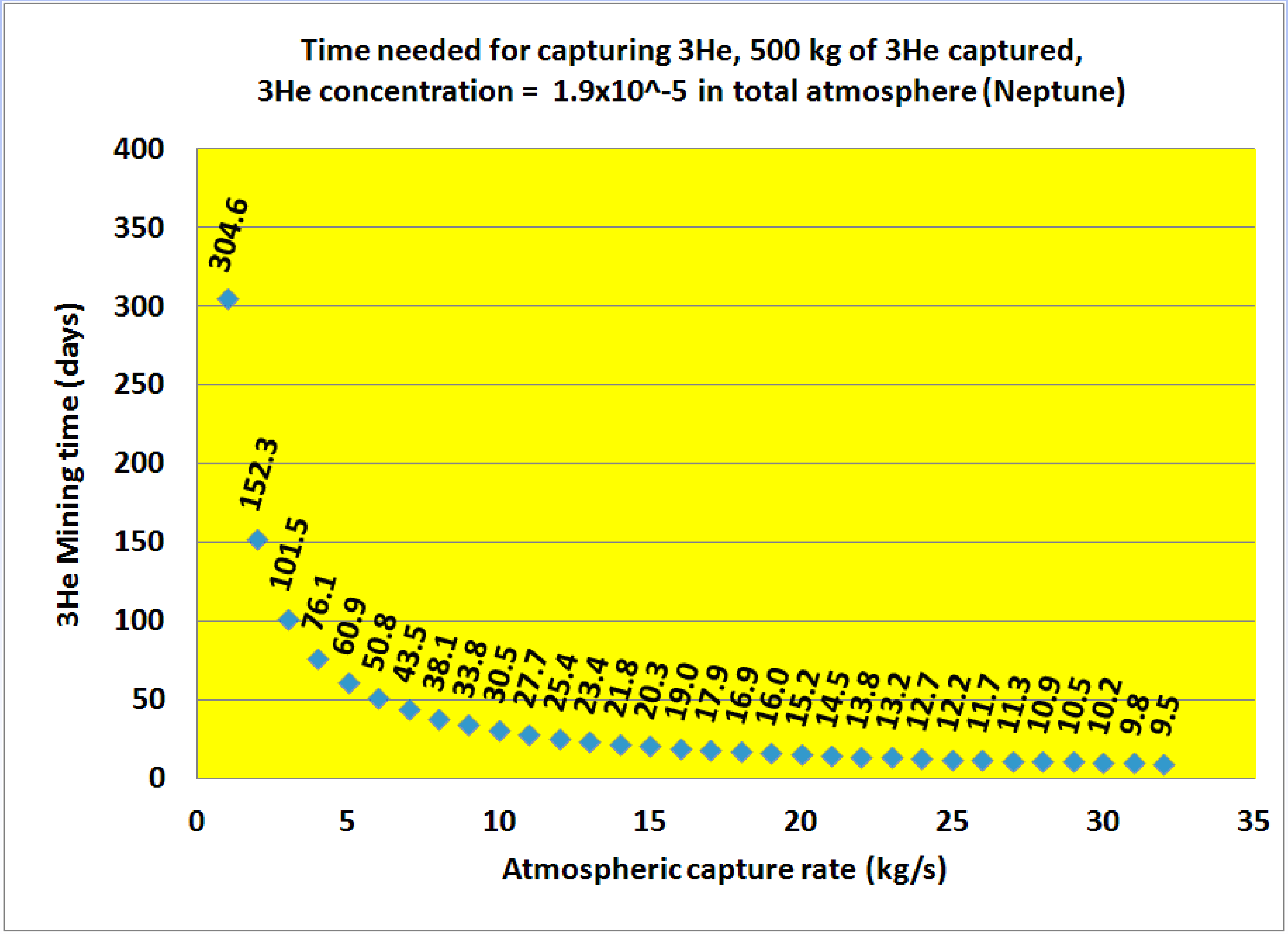
AMOSS NTP Designs: Solid Core and Gas Core



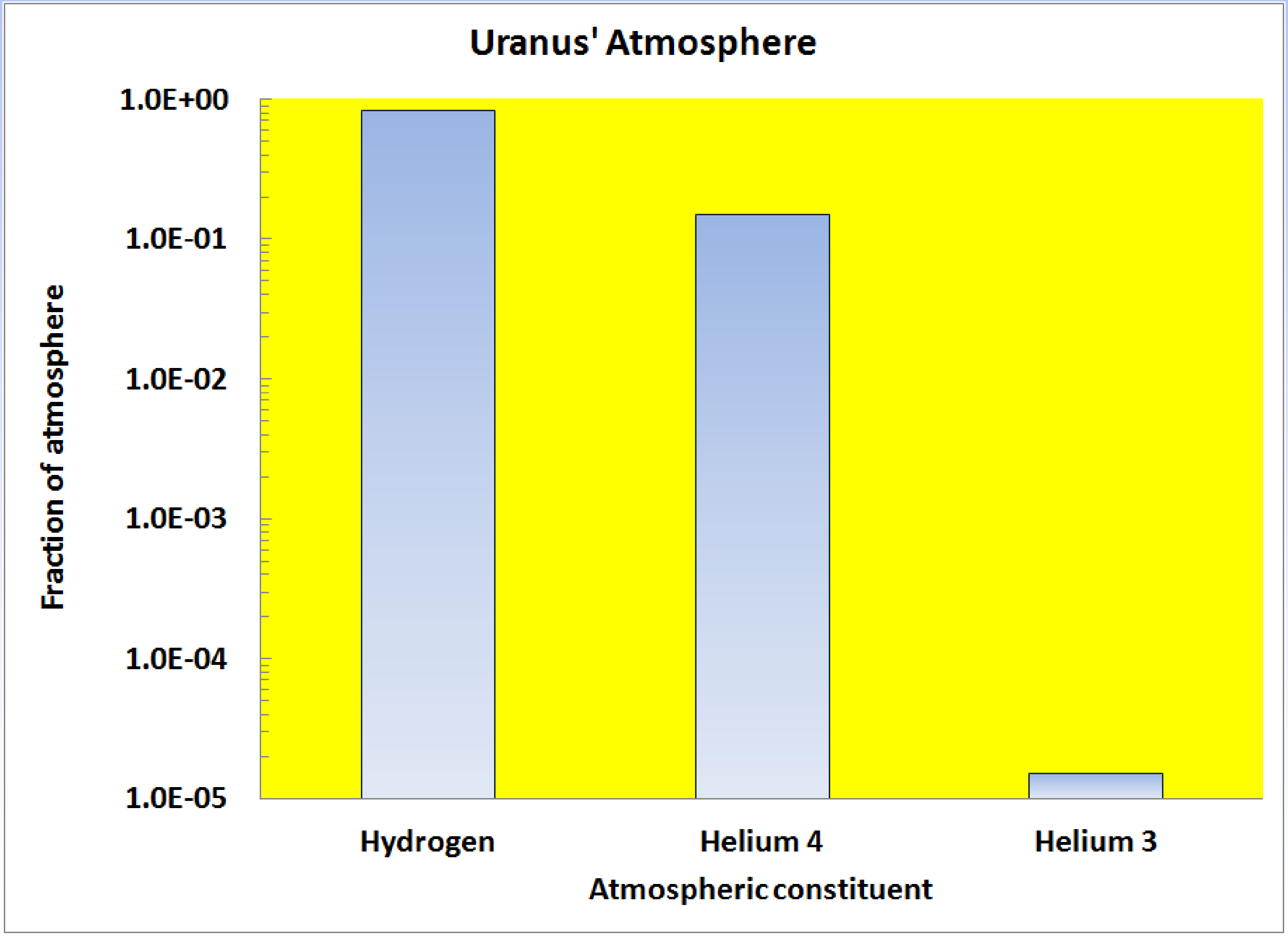
Time for 3He Capture at Uranus



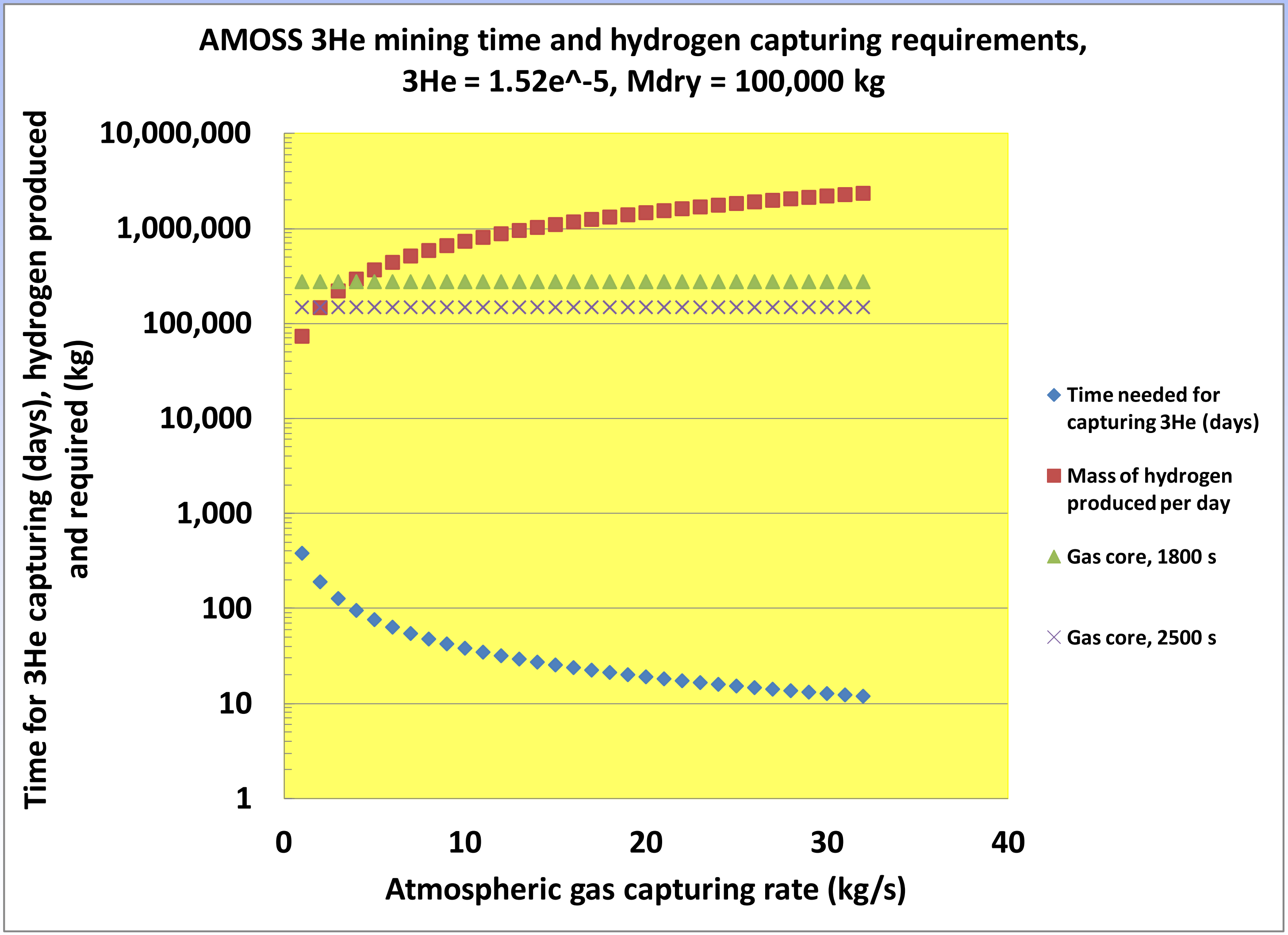
Time for 3He Capture at Neptune



Resource Capturing – Hydrogen, Helium 4, and Helium 3 Comparison, Uranus



AMOSS, Hydrogen Production at Uranus



AMOSS Constellation
Atmospheric Exploration Missions (1/2)

- **AMOSS helium 3 (3He) mining produces large amounts of additional hydrogen and helium.**
- **Given the fact that large amounts of hydrogen and helium are available, new missions can be conceived for vehicles in the outer planet atmosphere(s).**
- **Fleets of such aerospacecraft (ASC) vehicles could be fueled with AMOSS produced hydrogen and helium.**

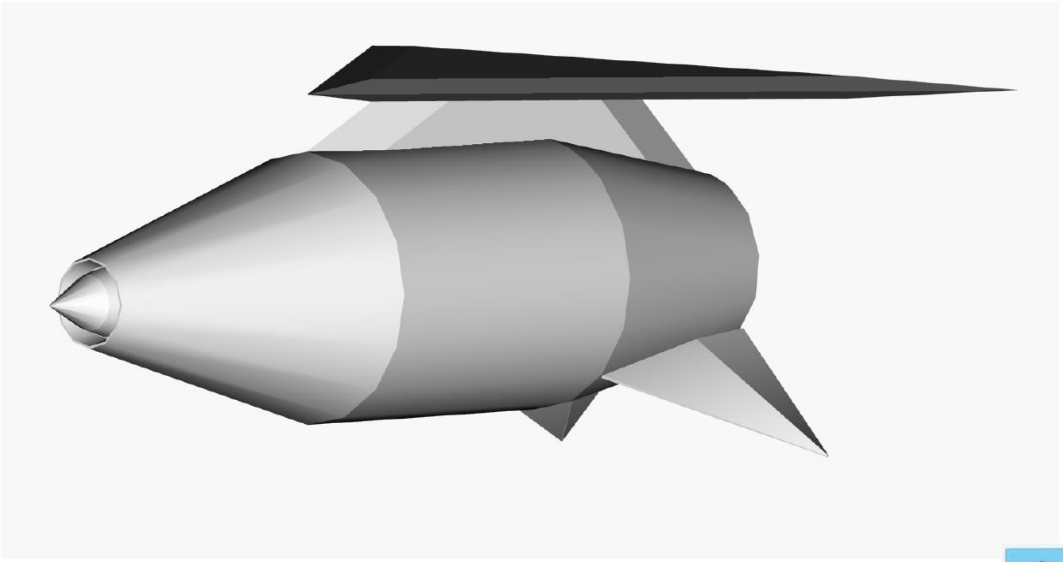
AMOSS Constellation
Atmospheric Exploration Missions (2/2)

- Potential missions include:
  - Aircraft for weather data gathering, weather warnings.
  - Deep diving subsonic “aircraft” probes that can go to low altitudes with 10X, 20X, 30X atmospheric pressures (a la scoopers).
  - Launching of GPS-ish vehicles to improve mining (ASC) communications.
  - Delivery of samples to orbital assets.

Exploration UAV size ranges		
Probe design	Mass (MT)	
Free fall	1	to 10
Parachute	1	to 10
Rocket boost	10	to 100
Rocket return	10	to 1,000
Long duration, subsonic	10	to 1,000
Aerospacecraft (mining)	100	to 10,000

UAV Configurations: High Speed (4a/4)

Nuclear Ramjet Flyer



UAV Configurations: High Speed (4b/4)

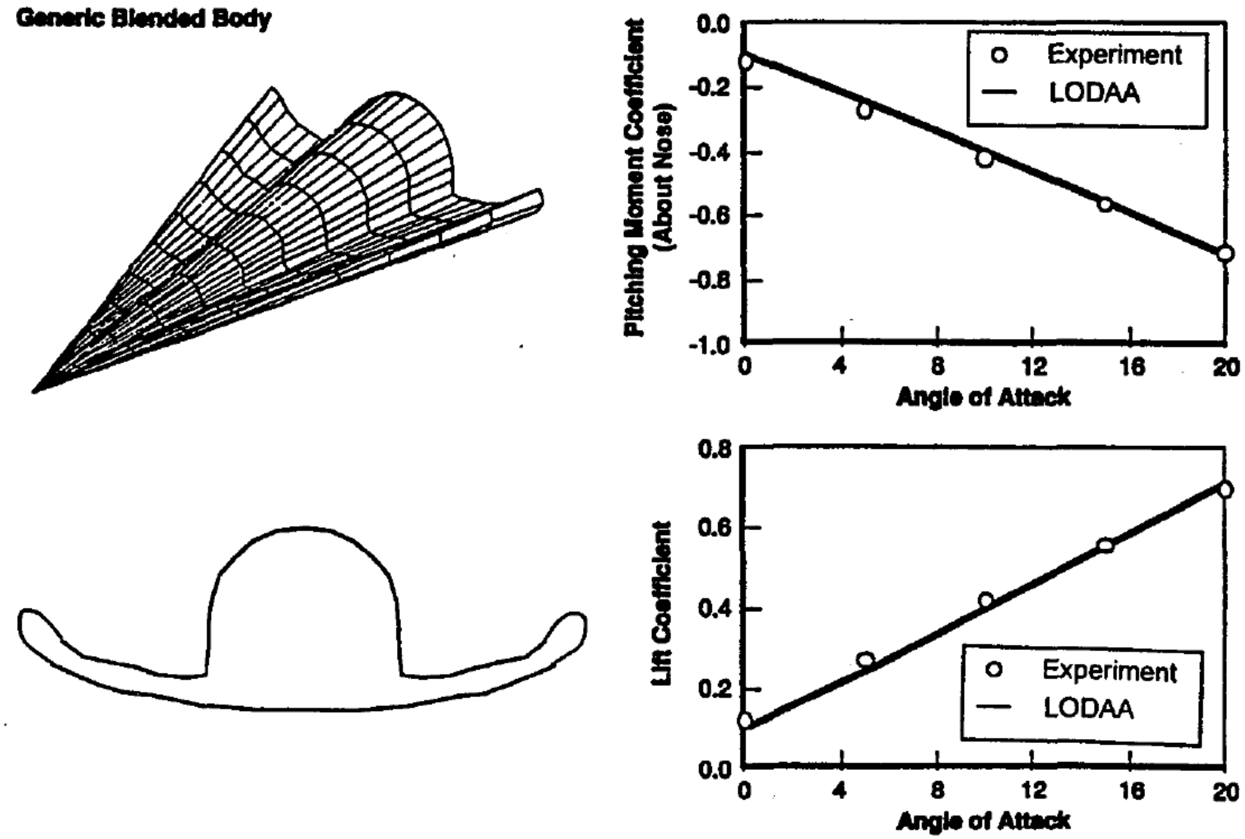
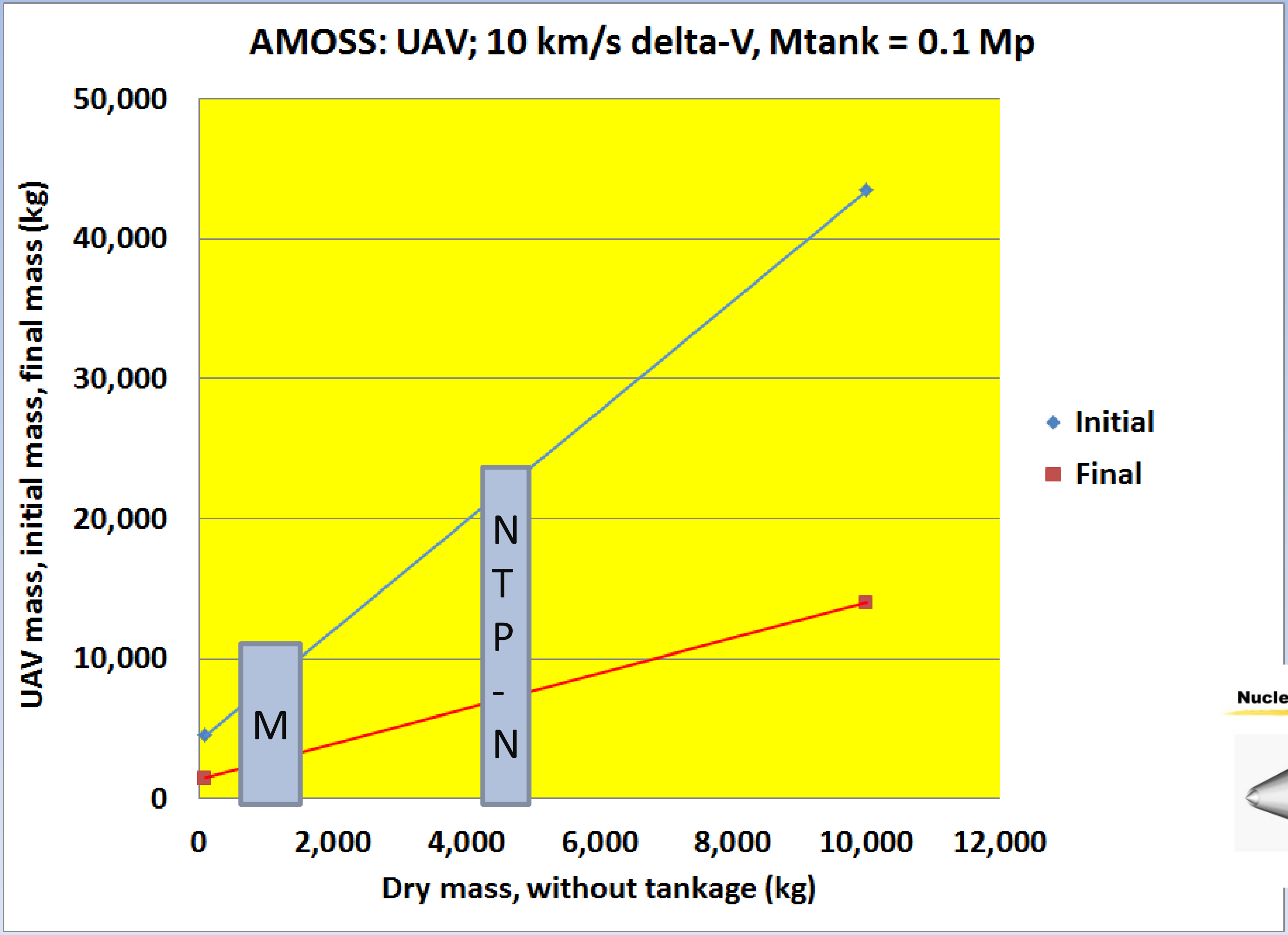
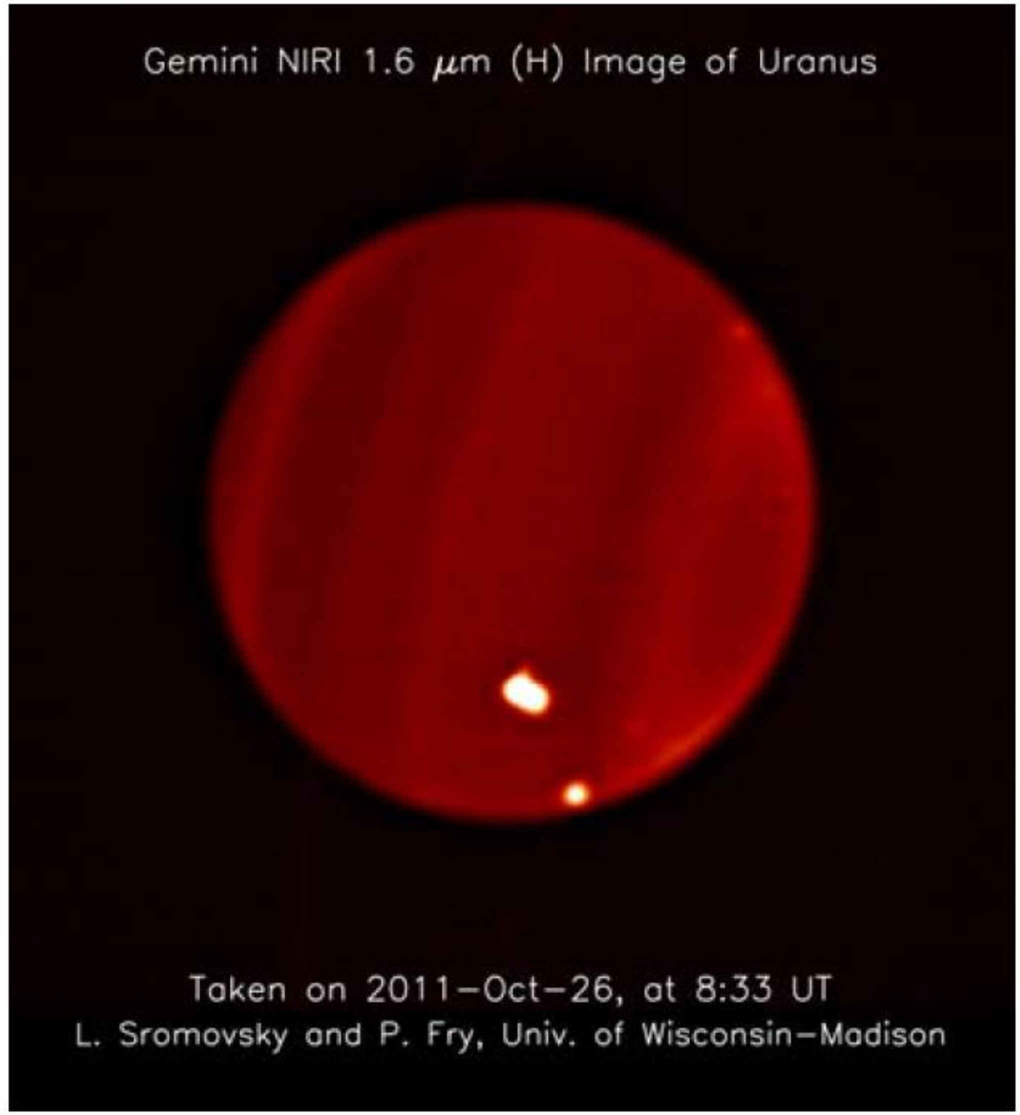


Figure 8. LODAA Predictions for a Blended Body Shape

UAV Configurations: High Speed (4c/4)



Uranus – Outer Planet Atmospheres and Wind Speeds



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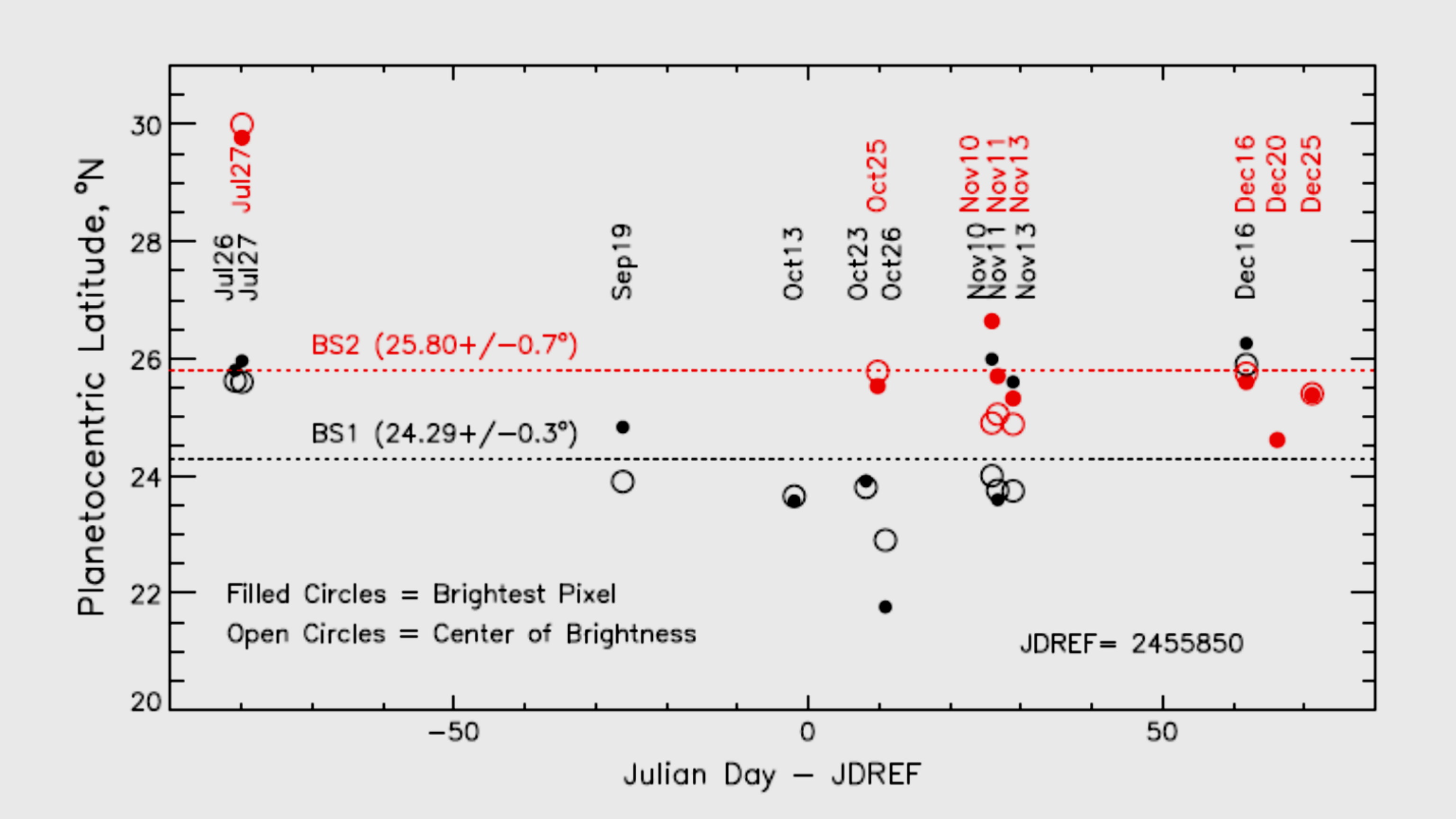
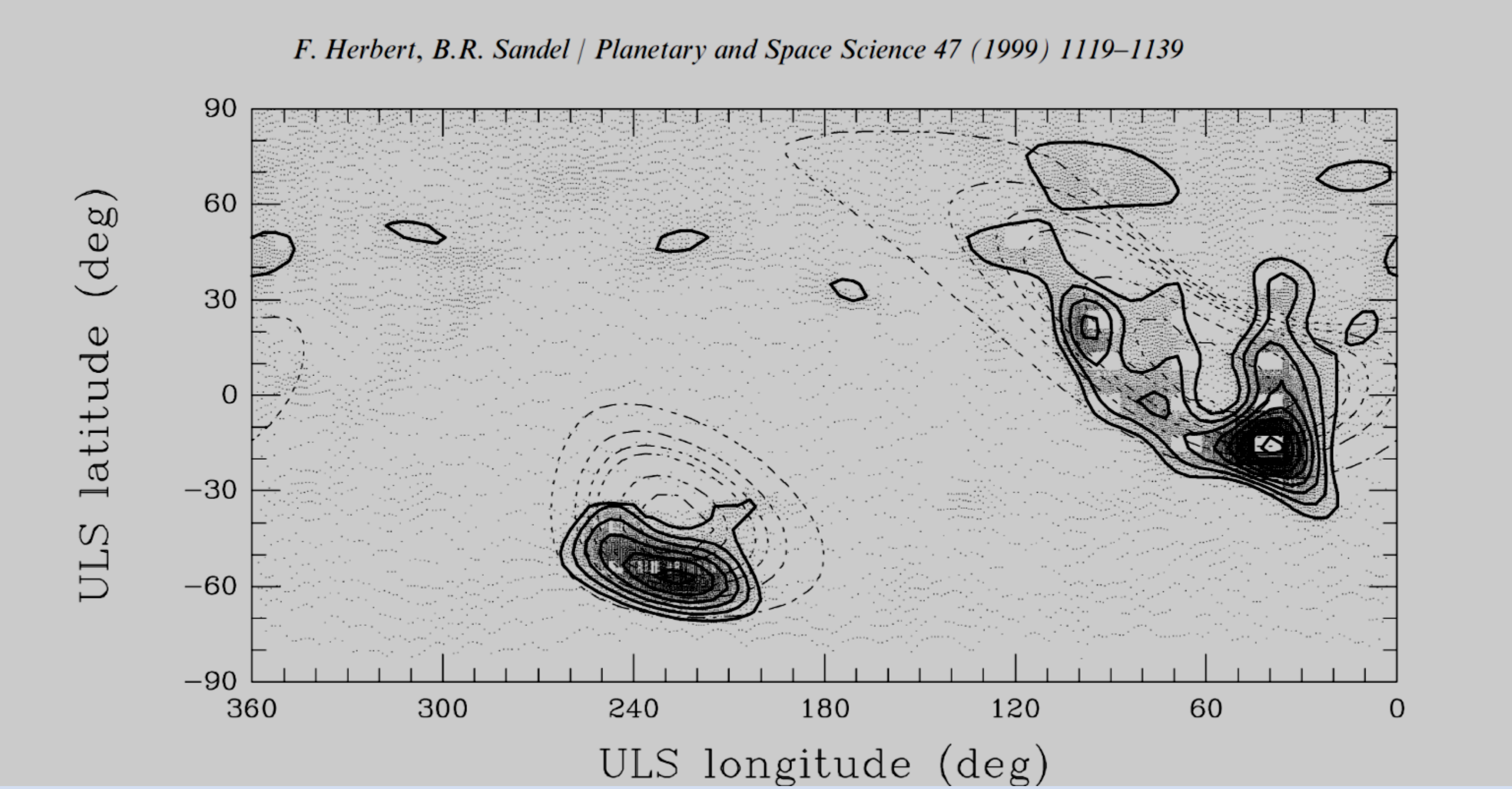
UAV Mission Planning: Weather Phenomena, Uranus



Uranus atmospheric phenomena (Reference 24)

UAV Mission Planning: Aurora Phenomena, Uranus



Uranus atmospheric phenomena (Reference 23)

UAV Configurations: Weather (3a/4)

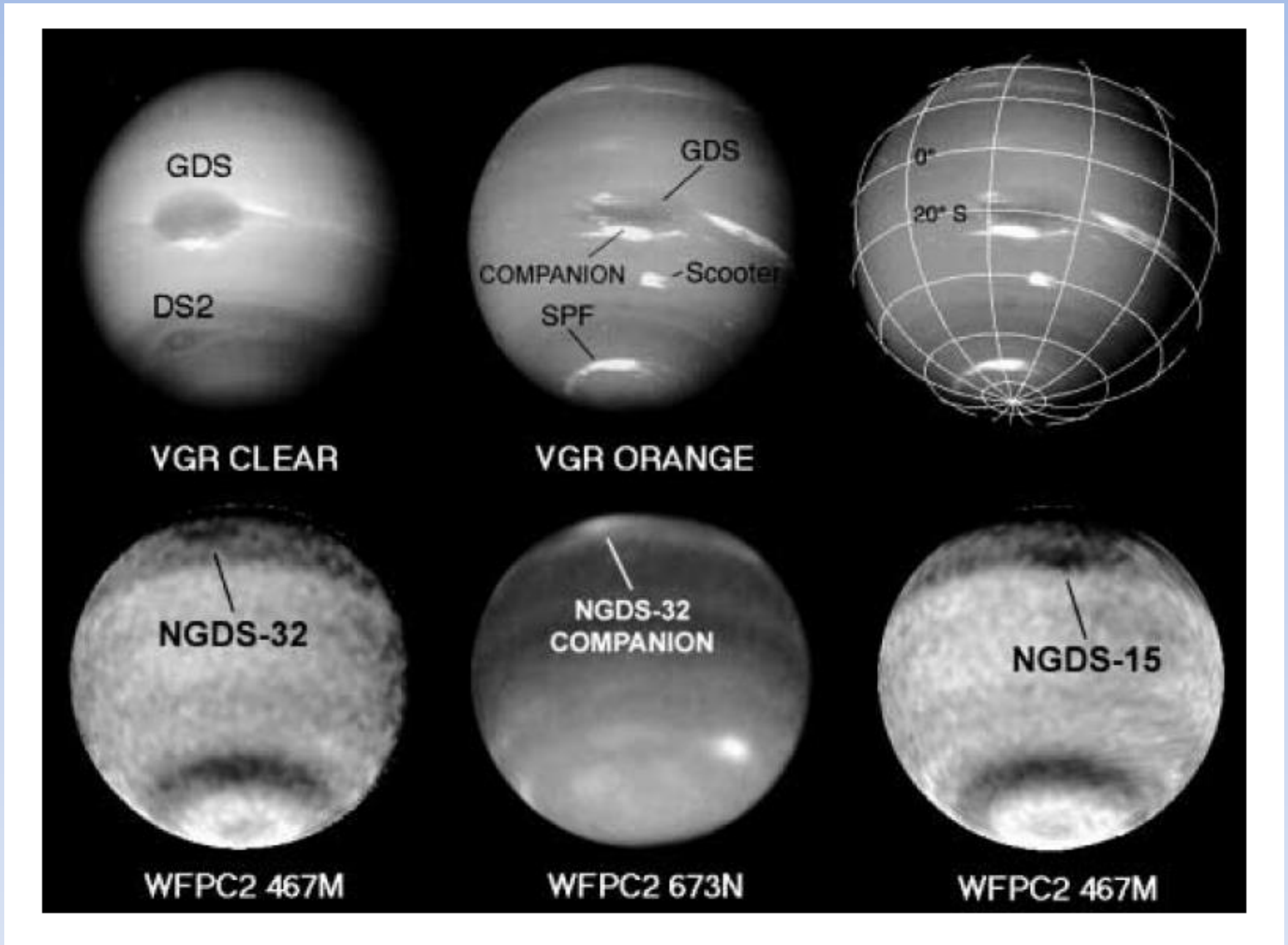
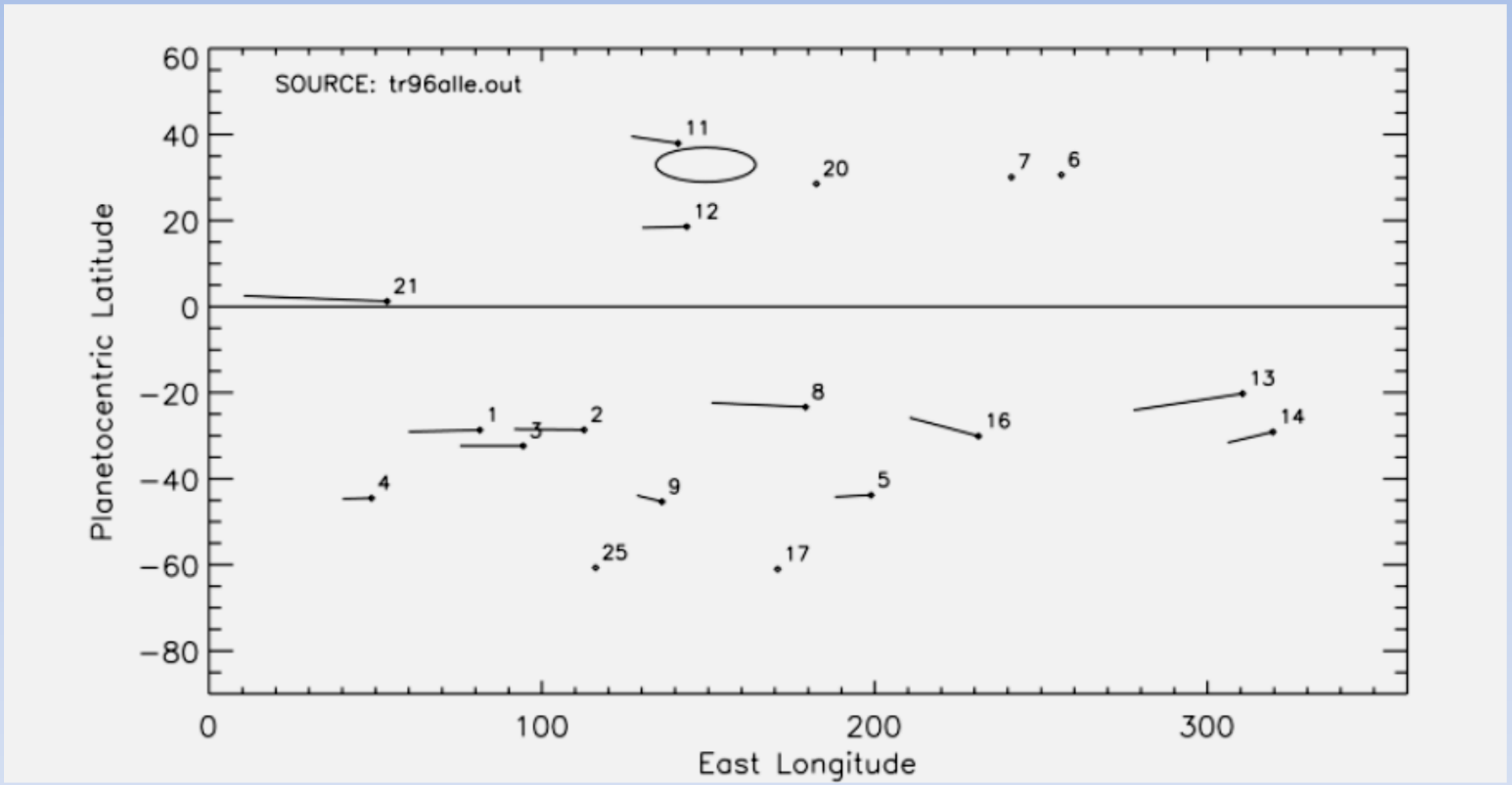


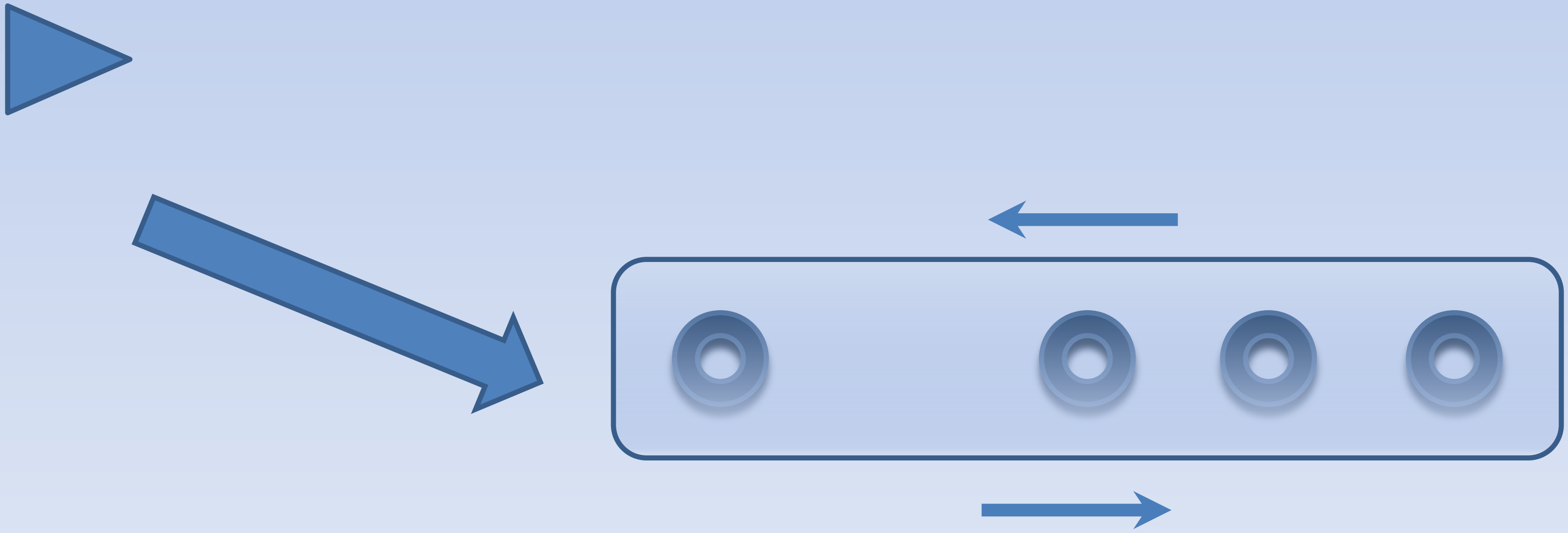
Figure B3. Neptune cloud features (Voyager, Hubble, Ref. 27)

UAV Mission Planning: Weather Phenomena: Neptune

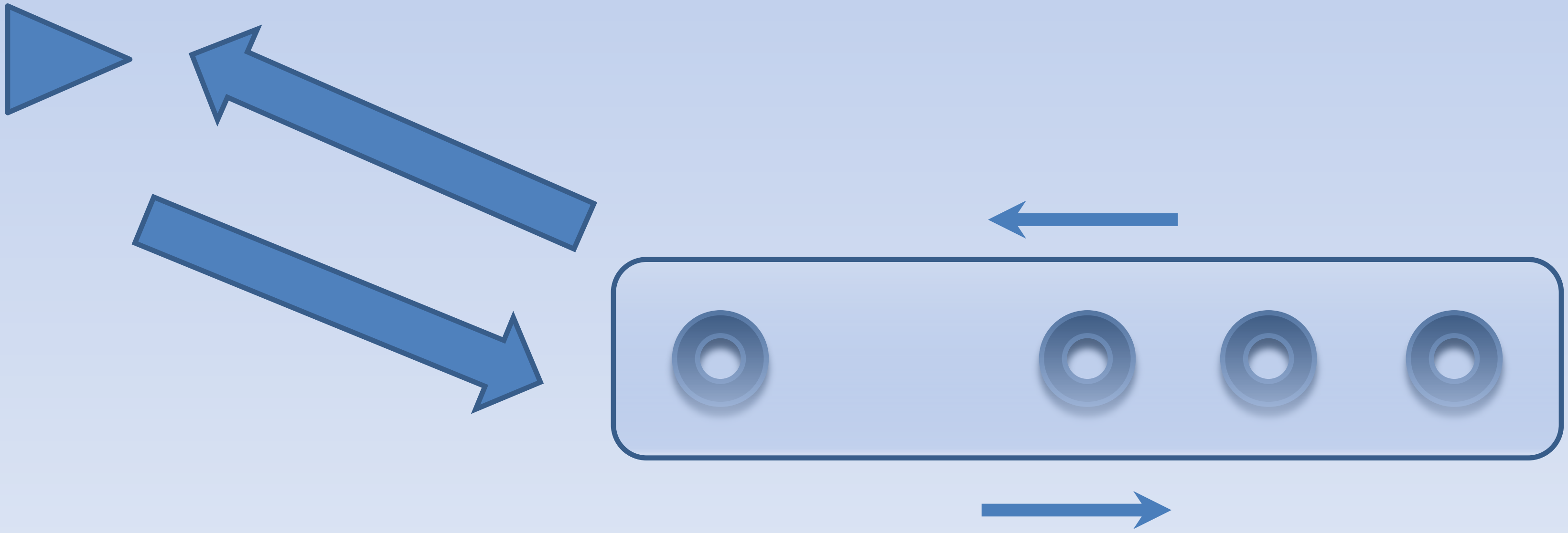


Neptune atmospheric phenomena (Reference 26)

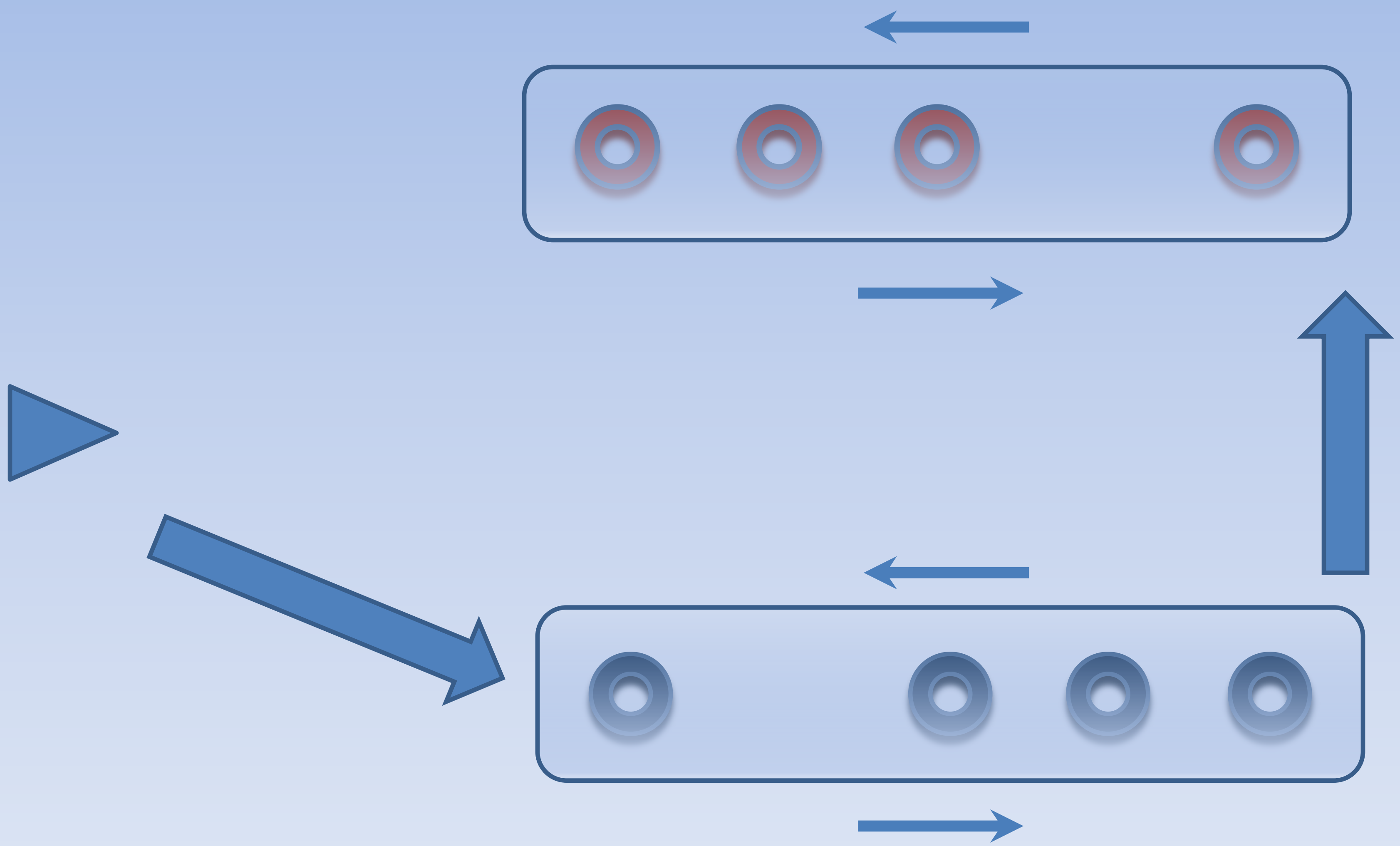
AMOSS UAV Mission Profiles
(Multiple Targets Assessed, One Way)



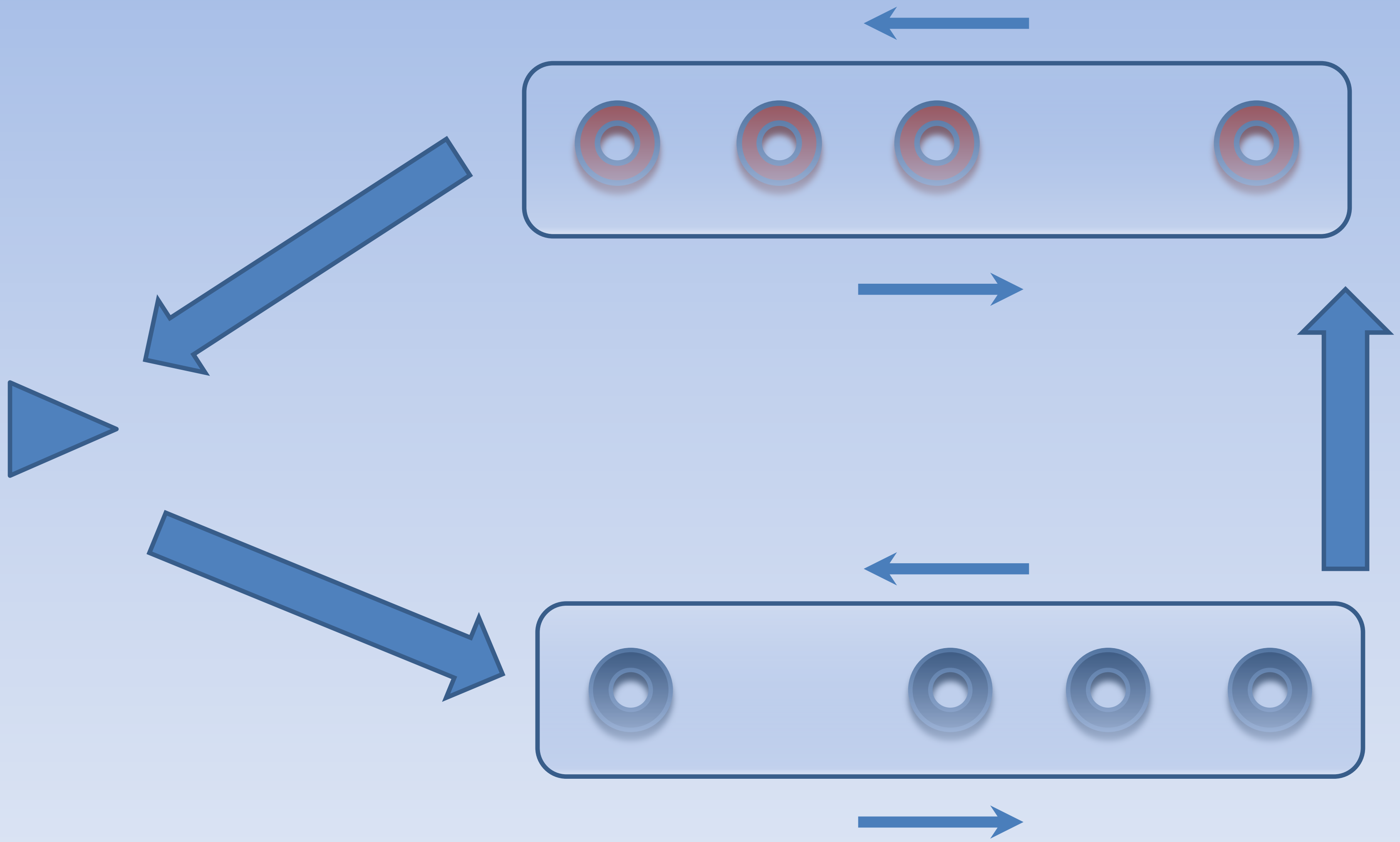
AMOSS UAV Mission Profiles
(Multiple Targets Assessed, Round Trip)



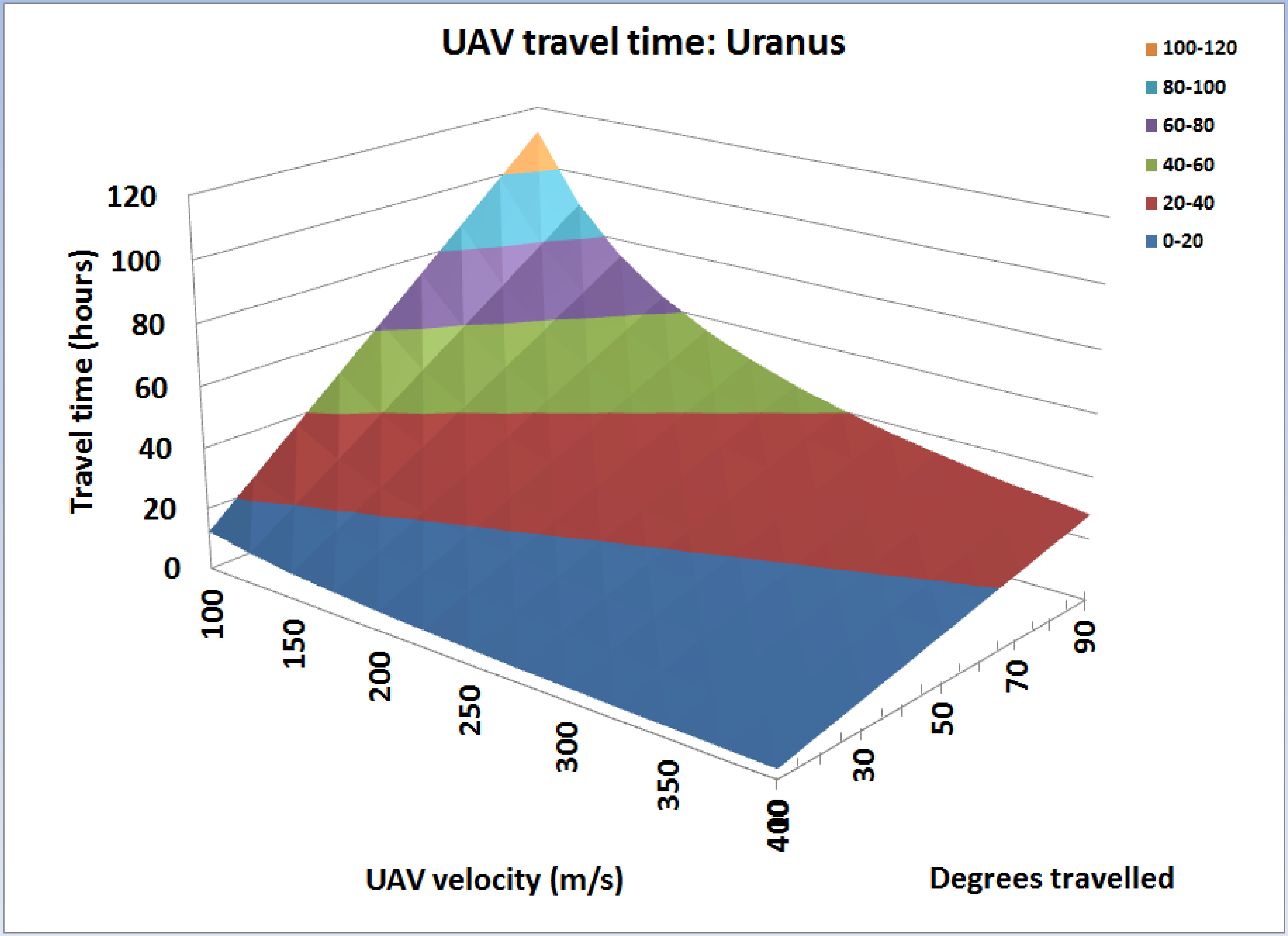
AMOSS UAV Mission Profiles
(Multiple Targets Assessed, Two Hemispheres, One Way)



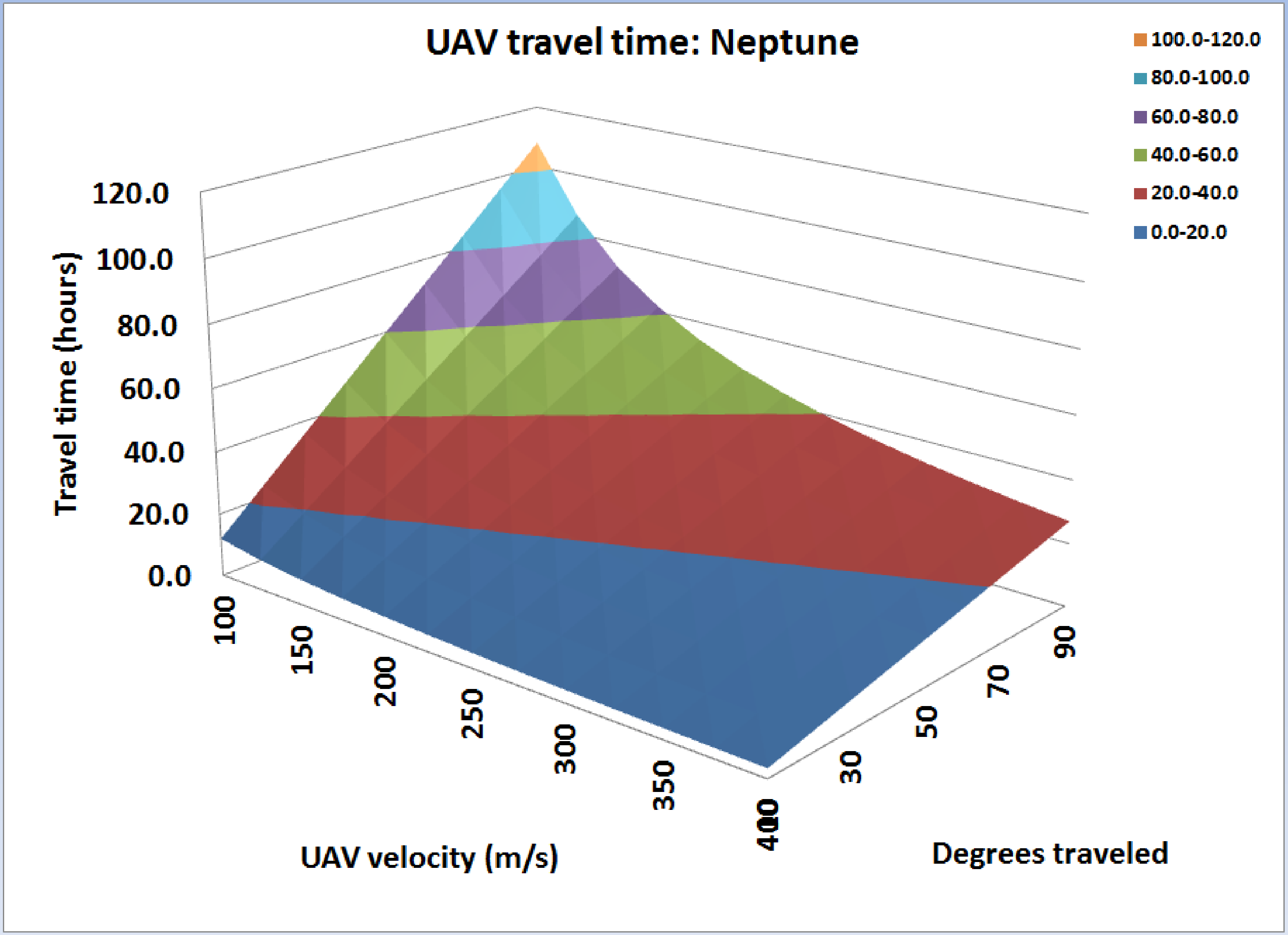
AMOSS UAV Mission Profiles
(Multiple Targets Assessed, Two Hemispheres, Round Trip)



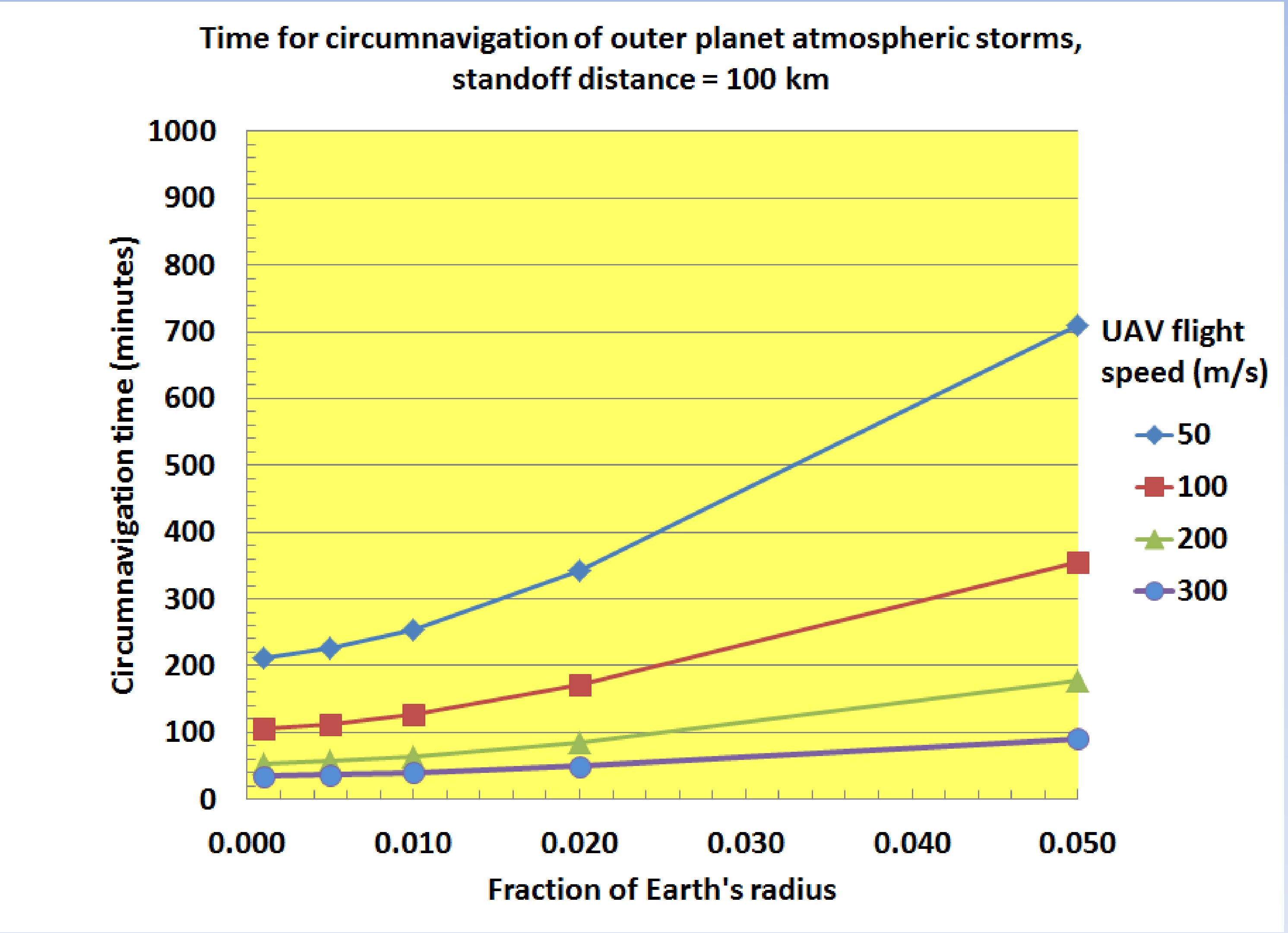
Travel Time Across Planet: Uranus



Travel Time Across Planet: Neptune



Time for Storm Circumnavigation



Resource Capturing – Observations (1/2)

- Helium 3 is the primary gas for capturing by aerospacecraft cruisers.
- While capturing helium 3, the cruiser also has the potential for capturing very large amounts of hydrogen and helium 4 (which comprise nearly 100% of the atmosphere).
- Resource capturing of hydrogen and helium 4 can lead to fueling fleets of smaller but specialized exploration and exploitation vehicles.
- New concepts for weather monitoring, cloud exploration, and deep-diving aircraft fueled by these large resources are possible.

Resource Capturing – Observations (2/2)

- Uninhabited Aerial Vehicle (UAV) and drone options may use nuclear ramjets or rockets.
- Sampling of the atmosphere and investigation of short- and long-term storm and weather related phenomena are options.
- Mission planning could allow for surveying many targets per UAV flight.
- Nuclear thermal propulsion reactor life may limit nuclear ramjet based aircraft to less than 40 hours.
- Rocket vehicles that deliver the ramjets to storm locations may allow for rapid responses to unique storms and other phenomena.

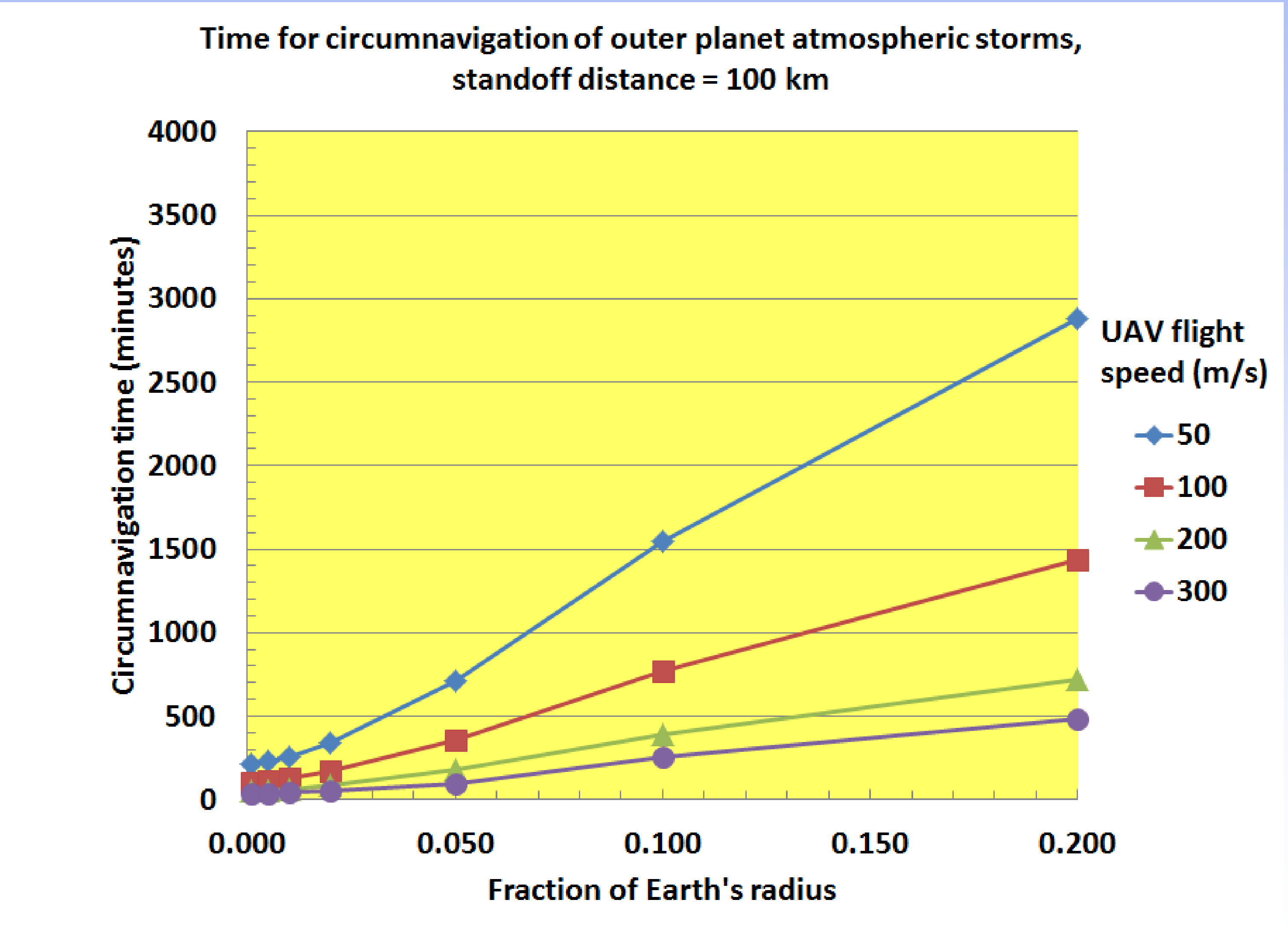
Concluding Remarks

- Atmospheric mining can open new frontiers.
- Gas core engines can reduce the vehicle initial mass by 72% to 80% over solid core NTP powered vehicles.
- AMOSS helium 3 capturing leads to processing huge amounts of gas for powering unique UAVs and atmospheric missions.
- Nuclear thermal propulsion reactor life may limit nuclear ramjet aircraft to less than 40 hours of operation.
- Rocket vehicles that deliver the ramjets vehicles to storm locations may allow for rapid responses to unique atmospheric phenomena.
- Let’s go to the stars, as quickly as possible.

Neptune

JPL

Time for Storm Circumnavigation



AMOSS UAV Mission Operations

Cruise, Rocket Return, Rocket Arrive, Multiple Targets

05-2014

AMOSS UAV Concept of Operations

AMOSS UAV Concept of Operations (CONOPS)

UAV arrives in atmosphere (Earth delivery)

UAV fueling from aerospacecraft / tanker

UAV departs vicinity of aerospacecraft / tanker

UAV performs rocket arrival maneuver

UAV arrives at target 1

UAV cruises at speeds for science measurements

UAV departs vicinity of target 1

UAV cruises to target 2

UAV arrives at target 2

UAV cruises at speeds for science measurements

UAV departs vicinity of target 2

At end of target investigation(s):

- UAV can perform cruise to return to the aerospacecraft / tanker
- UAV can perform terminal maneuver, ending mission

AMOSS UAV Concept of Operations

UAV arrives in atmosphere (Earth delivery)		
UAV fueling from aerospacecraft / tanker		
UAV departs vicinity of aerospacecraft / tanker		
UAV performs rocket arrival maneuver		
UAV arrives at target 1		
UAV cruises at speeds for science measurements		
UAV departs vicinity of target 1		
UAV cruises to target 2		
UAV arrives at target 2		
UAV cruises at speeds for science measurements		
UAV departs vicinity of target 2		
At end of target investigation(s):		
	UAV can perform cruise to return to the aerospacecraft / tanker	
	UAV can perform terminal maneuver, ending mission	